U.S. OIL IMPORT VULNERABILITY

The Technical Replacement Capability

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Foreword

Iraq's invasion of Kuwait in August 1990 triggered a long-dormant awareness of this Nation's vulnerability to disruptions in foreign oil supplies. Amid heightened concern over the potential impacts on U.S. oil supplies of prolonged hostilities in the Middle East, the Senate Committee on Energy and Natural Resources asked OTA to update the conclusions of our 1984 report, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*. The Subcommittee on Energy and Power of the House Committee on Energy and Commerce subsequently joined in the request.

This report examines the changes that have taken place in world oil markets and the U.S. economy since 1984 and provides revised estimates of the technical oil replacement potential that might be attained in the event of a severe and long lasting cutoff of imported oil. The analysis focuses on technologies that are commercially available today or will be within the next 5 years and that are among the most cost-effective methods for replacing oil use in applicable sectors. It also considers the economic impacts of adopting an aggressive oil replacement strategy in a severe oil emergency. The report presents a variety of policy options that could help accelerate the adoption of oil replacement technologies in preparation for, or in response to, a severe supply disruption, or as part of a long-term national policy to reduce import vulnerability.

The report's conclusion that U.S. capability to replace lost oil imports is shrinking should be sobering to those who believe that there are quick and easy technological solutions, or that market forces alone will be sufficient to overcome the substantial economic and social dislocations that could result from a prolonged major oil disruption.

Operation Desert Storm and the return to low world oil prices have lessened the immediacy of concerns over import dependence. But this latest oil scare has refocused attention on the Nation's energy policies and where they may lead us.

This report is one of four just-completed OTA studies on energy technology and policy issues. The others are: *Energy Technology Choices: Shaping Our Future* (July 1991), *Energy Efficiency in the Federal Government: Government by Good Example?* (May 1991), and *Improving Automobile Fuel Economy: New Standards, New Approaches* (October 1991). We hope that these studies will prove helpful to Congress as it considers proposed energy legislation.

This study enjoyed the strong support and encouragement of Michael T. Halbouty of the Technology Assessment Advisory Council, who generously shared his wisdom gained from years in the oil patch. OTA is grateful for his advice and counsel.

OTA also appreciates the assistance of the individuals and organizations who provided substantial assistance to our staff and contractors. To them and to the workshop participants, reviewers, and contractors who contributed to this report, we extend our gratitude.

John H Gibbons

JOHN H. GIBBONS
Director

OTA Workshop on Oil Supply Disruption: Oil Replacement Capability

John Amoruso
Amoruso Petroleum Co.

David Block
Florida Solar Energy Center

Joe Corns
Industrial Analysis and Forecasting

Dan Dreyfus
Gas Research Institute

K.G. Duleep
Energy & Environmental Analysis, Inc.

Pete Franolic
Bethlehem Steel Corp.

Brad Hollomon
New York State Energy Research
and Development Administration

Bjorn M. Kaupang
General Electric Co.

Mark Ledbetter
American Council for an
Energy Efficient Economy

Barry McNutt
U.S. Department of Energy

Mark Rodekohr
U.S. Department of Energy

Glenn Schleede
New England Electric System

Raymond Schmidt
Supervisor

NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the participants in the workshops. The workshop participants do not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

OTA Project Staff—U.S. Oil Import Vulnerability: The Oil Replacement Capability

Lionel S. Johns, *Assistant Director, OTA*
Energy, Materials, and International Security Division

Peter D. Blair, *Energy and Materials Program Manager*

Karen L. Larsen, *Project Director*

Lillian Chapman, *Office Administrator*
Linda Long, *Administrative Secretary*
Phyllis Brumfield, *Secretary*

Kathryn Van Wyk, *Editor*

Contractors

Renova Engineering, P.C., Staten Island, NY
Hillard Huntington, Stanford University, Stanford, CA
John Weyant, Stanford University, Stanford, CA

Contributors and Reviewers

David Block
Florida Solar Energy Center

Tom Bull
U.S. Food and Drug Administration

Steve Clifton
Houston Industries, Inc.

Joe Corns
Amoco Corp., MC 2906

Paul De Rienzo
ReNova Engineering

Michael T. Halbouty
Michael T. Halbouty Energy Co.

Brad Hollomon
New York State Energy Research
and Development Administration

Richard Iteilag
American Gas Association

Donald Jost
Sun Refining & Marketing

Dolores Kern
National Coal Association

Charles W. Linderman
Edison Electric Institute

David Montgomery
Charles Rivers Associates

Sashank Nadgauda
ReNova Engineering

Roger Naill
Applied Energy Services, Inc.

Jim Pavle
American Gas Association

Steven Plotkin
Office of Technology Assessment

Glen Schleede
New England Electric System

Jeffrey Seisler
Natural Gas Vehicles Coalition

Stephen L. Thumb
Energy Ventures Analysis, Inc.

Jan Vlcek
Industrial Oil Consumers Group

Eugene W. Zeltmann
General Electric

Mary Beth Zimmerman
Alliance to Save Energy

Contents

Page

Chapter 1. Introduction and Summary 3

Chapter 2. Oil in the U.S. Economy 29

Chapter 3. U.S. Technical Potential for Replacing Oil 47

Chapter 4. Economic Aspects of Oil Replacement Strategies 105

Chapter 5. U.S. Energy Policy and Technologies for Replacing Imported Oil 115

Appendix A: Reference Maps 135

Chapter 1

Introduction and Summary

Contents

Page
BACKGROUND 3
WHAT HAS CHANGED? 3
  Patterns of Oil Supply and Demand 4
  Major Changes 4
OVERVIEW OF U.S. OIL REPLACEMENT POTENTIAL 7
  Methodology and Assumptions 8
  Technical Replacement Capability 8
IMPLICATIONS OF GROWING OIL IMPORT DEPENDENCE AND ERODING OIL REPLACEMENT CAPABILITY 12
MAJOR OPPORTUNITIES FOR REDUCING OIL IMPORT DEPENDENCE 13
  Automotive Fuel Economy 14
  Alternative Transportation Fuels 15
  Increased Domestic Production 16
  Diversity in Oil Supply 18
LOOKING TOWARD THE FUTURE—SCENARIOS FOR REDUCING OIL DEPENDENCE 18
POLICY CONSIDERATIONS 20
  Replacing Oil Use in a Severe Import Disruption 21
  Reducing Oil Import Vulnerability as Part of Long-Term National Energy Policy 25
CONCLUSION 26

Figures

Figure *Page*
1-1. World Oil Consumption 1983 and 1989 4
1-2. Total U.S. Oil Imports and Imports From the Middle East, 1989 5
1-3. U.S. Petroleum Products Supplied by Type 5
1-4. U.S. Energy and Oil Consumption, 1989 6
1-5. U.S. Energy and Oil Intensity 7
1-6. Oil Replacement Potential by Sector, 1984 10
1-7. U.S. Oil Replacement Potential Technical Capability by Sector, 1991 10
1-8. Estimated Car and Light-Truck New Fuel Economy and Gasoline Prices, 1978-90 15
1-9. U.S. Oil Supply and Demand Futures Baseline Projection: Current Trends in Domestic Oil Production, Net Imports, and 1989 New Car Fuel Economy 19
1-10. U.S. Oil Supply and Demand Futures: Impacts of Increased Domestic Oil Supply and Improved Fuel Economy 19
1-11. U.S. Oil Supply and Demand Futures, Impacts of Improved Domestic Oil Supply and Fuel Economy, and Oil Backout 20

Tables

Table *Page*
1-1. Estimated Oil Replacement Potential, 1984 9
1-2. Summary of Estimated Oil Replacement Potential, 1991 9
1-3. OTA Estimates of Potential Short-Term Fuel Economy Gains 15

Chapter 1

Introduction and Summary

BACKGROUND

The 1991 war in the Middle East has once again focused world attention on the geopolitics of that region. In the United States, energy security has returned to the national policy agenda after nearly a decade of absence. In response to renewed concerns, OTA has been asked to reexamine the U.S. technical capability for coping with a sustained disruption in oil supply.

Seven years ago, at the request of the Senate Committee on Foreign Relations, OTA published the report *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*[1], which analyzed the supply and demand technologies that could replace a shortfall of 3 million barrels per day (MMB/D) in U.S. oil supply over a 5-year period. In August 1990, following the Iraqi invasion of Kuwait, the Senate Committee on Energy and Natural Resources asked OTA to revisit the findings of its 1984 report to examine how changes in world oil markets and in the geopolitical setting have affected the technical potential for oil replacement and, consequently, the candidate policy options. Early in 1991, the Energy and Power Subcommittee of the House Committee on Energy and Commerce endorsed the Senate request. This report responds to that request.

WHAT HAS CHANGED?

In our 1984 assessment, we assumed a scenario of an immediate loss of imported oil of 3 MMB/D, beginning in mid-1985 and continuing for at least 5 years.[2] The scenario was equivalent to a curtailment of 70 percent of U.S. net imports and a loss of 20 percent of U.S. oil supplies. Our analysis concluded that the United States had the technical capability to replace 3.6 MMB/D of oil over the projected period. Thus, U.S. oil replacement capability in 1984 exceeded the assumed serious oil import curtailment by the considerably comfortable margin of 600,000 barrels per day (B/D).

By 1990, the picture had clouded. U.S. petroleum consumption had risen from 15 to 17 MMB/D, while domestic production slipped from 10.3 to 9.2 MMB/D. Oil imports had risen from 5 to 8 MMB/D, and the share of U.S. oil needs supplied by imports had increased from 33 to over 40 percent. If we faced an oil disruption today comparable in magnitude to the scenario assumed in our 1984 report (i.e., a curtailment of all 15 MMB/D of Persian Gulf exports), the impacts could be devastating. The short–fall in U.S. oil imports could be as high as 5 MMB/D, still 70 percent of net imports, however, it would represent 30 percent of U.S. oil supplies. Moreover, reliance on technical means alone to replace lost oil imports would prove insufficient. OTA estimates that currently available oil replacement technologies could displace only about 2.9 MMB/D of 1989 oil use within 5 years. This replacement potential must be offset by the expected continuing decline in domestic oil production, yielding an effective import replacement capability of from 1.7 to 2.8 MMB/D. Thus the present U.S. potential to respond to a serious and prolonged oil shortage is less than it was in 1984 and would fall several million barrels short of the 5 MMB/D cutoff assumed in our 1991 disruption scenario.

Fortunately, many experts believe that the probability of a serious and prolonged disruption of the magnitude assumed in our analysis is very low. Surge production capacity, voluntary conservation measures, and private and government stockpiles were sufficient to allow oil consumers to weather the most recent oil disruption. However, our analysis suggests that as the current world surplus in oil production capacity is reduced the U.S. could face serious difficulties in responding to major oil supply disruptions that persist for more than a few months.

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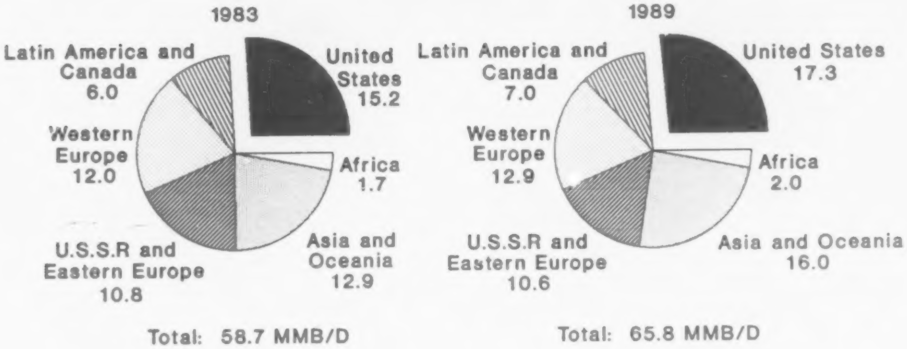
[1] U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Washington, DC: U.S. Government Printing Office, September 1984), available from the National Technical Information Service, Springfield, VA 22161, NTIS order #PB 85-127 785/AS. Hereinafter referred to as *The Oil Replacement Capability*.

[2] The United States has never faced a supply disruption of such magnitude and duration. Most studies have assumed that an oil cutoff would last 1 or 2 years, but an indefinite shortfall is not implausible. Political upheavals, war, and natural or manmade disasters in the Middle East oil regions could have such a result. Indeed, the long-lasting oil price increases resulting from the 1970s disruptions were the economic equivalent of a lasting supply shortfall. Between 1978 and 1983, the real price of oil increased 60 percent, and there was an unadjusted decline in oil demand of nearly 4 MMB/D. Ibid., p. 9.

Figure 1-1—World Oil Consumption 1983 and 1989
(million barrels per day)



SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *International Energy Annual 1991*, DOE/EIA-0219 (89) (Washington, DC: U.S. Government Printing Office, February 1991), table 8.

In the following, we note the more significant changes in U.S. oil supply and use since 1984 and explore the implications for our current concern over U.S. import dependence.

Patterns of Oil Supply and Demand

Today, the world consumes about 65 MMB/D of oil, up 12 percent from 58.7 MMB/D in 1983 when the 1984 OTA assessment was completed. The United States consumes about 17 MMB/D, which continues to be over 25 percent of the total world consumption. U.S. oil consumption has risen by about 14 percent since 1983; however, U.S. domestic production is down sharply, with the result that net imports have risen from about one-third of total U.S. consumption in 1983 to over 40 percent in 1990.[3] Moreover, the fraction of total oil imports coming from Persian Gulf nations has increased from about 4 percent of total U.S. oil consumption (10 percent of total U.S. oil imports) to over 11 percent (25 percent of gross U.S. oil imports in 1990). (See figures 1-1 and 1-2.)

Present patterns of U.S. oil consumption in the aggregate are very similar to those of 1983. The relative proportions of consumption by product category (e.g., gasoline, middle distillates, fuel oil) are quite similar to those of 1983, with about 42 percent of oil consumed as gasoline (see figure 1-3). Industrial and transportation use of oil have both grown about 13 percent since 1983, residential and commercial use has grown only 9 percent, and electric utility use has remained almost unchanged. However, since industrial and transportation applications together approach 90 percent of U.S. oil use, the relative proportions of oil use across end-use sectors remain about the same as in 1983—transportation (63 percent), industrial (25 percent), residential and commercial (8 percent), and electric utilities (5 percent). (See figure 1-4.) The various oil products and their uses are described in more detail in chapter 2.

Major Changes

Advances in technology and resource discovery, price trends, changes in U.S. and world economic structure, and policy shifts have all altered—in some cases, dramatically—the context within which decisions about U.S. oil use and supply are made by industry, government, and consumers. The following are the major changes that have occurred in the last two decades:

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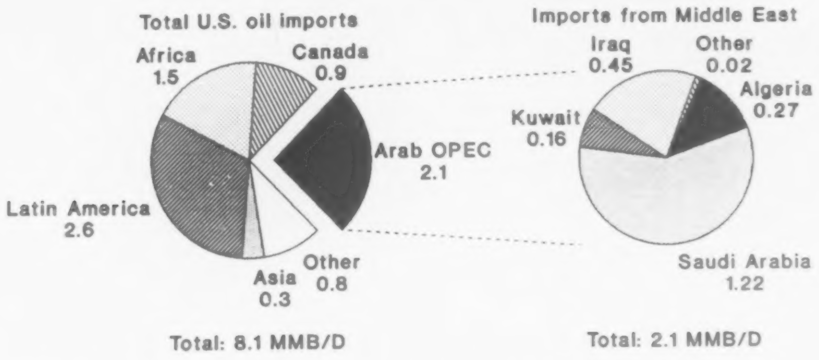
[3] Two OTA reports have examined the pressures on the domestic oil industry and the factors that will influence future production. See U.S. Congress, Office of Technology Assessment, *Oil Production in the Arctic National Wildlife Refuge: The Technology and the Alaskan Oil Context*, OTA-E-394 (Washington, DC: U.S. Government Printing Office, February 1989); and U.S. Congress, Office of Technology Assessment, *U.S. Oil Production: The Effect of Low Oil Prices*, Special Report, OTA-E-348 (Washington, DC: U.S. Government Printing Office, September 1987), available from the National Technical Information Service, Springfield, VA 22161, NTIS order #PB 88-243 548.

Figure 1-2—Total U.S. Oil Imports and Imports From the Middle East, 1989
(millions of barrels per day)



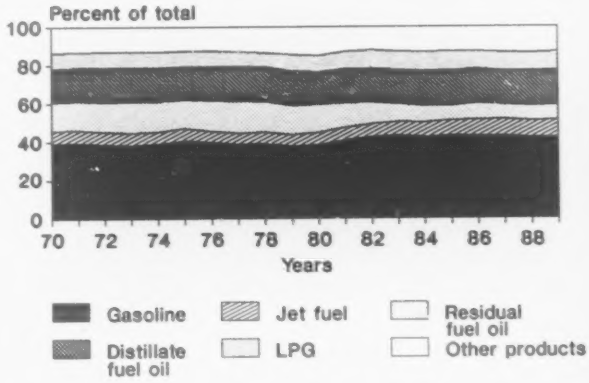
SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Annual 1989*, DOE/EIA-0340(89) vol. 1 (Washington, DC: U.S. Government Printing Office, May 1990), table 21.

Improved U.S. Energy Efficiency—Energy efficiency has increased considerably in all sectors of the economy and has entailed many permanent structural changes, including improvements in both the efficiency and flexibility of energy-using technologies.[4] For example, automotive fuel economy, industrial boiler and electric power plant fuel efficiency have all improved substantially. Nonetheless, many opportunities to improve efficiency remain, although they may be more difficult to secure without raising energy prices.[5]

Decreased Oil Intensity—The considerable shift from oil use by industry and electric utilities in the 1970s and 1980s resulted in a decline in oil intensity (oil used per dollar of gross national product (GNP); see figure 1-5). Improvements in energy efficiency and the shift to other fuels (especially natural gas, coal, and nuclear energy) contributed to the decline.

Increased Strategic Petroleum Reserve (SPR)—The United States now has an SPR of approximately 568 million barrels of crude oil, the equivalent of about 90 days of net crude oil imports for the first half of 1991. Similarly, Europe and Japan have added to their strategic storage, although not to the same extent as the United States. The SPR was tapped for the first time during the Persian Gulf Crisis, initially in a congressionally approved test drawdown, and later as

Figure 1-3—U.S. Petroleum Products Supplied by Type*
(percent of total 1970-1989)



*Petroleum products supplied is an approximation of petroleum consumption.

SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 60.

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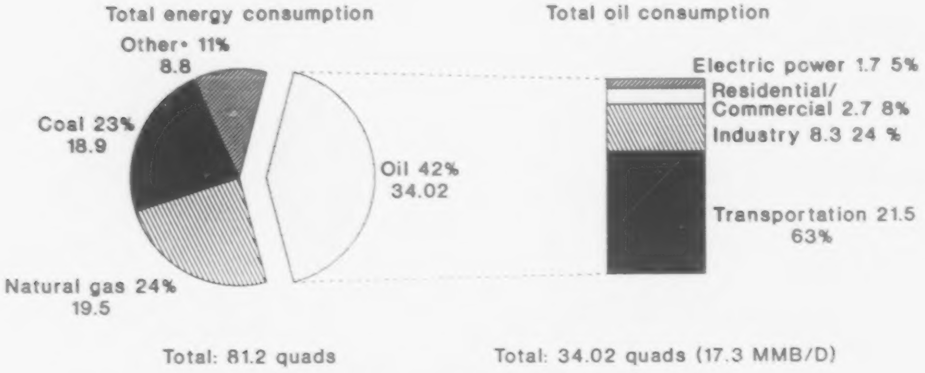
[4] See U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988), available from the National Technical Information Service, Springfield, VA 22161, NTIS order #PB 88-214 127/AS.

[5] OTA is examining this in more depth in its ongoing assessment, *U.S. Energy Efficiency: Past Trends and Future Opportunities*.

Figure 1-4—U.S. Energy and Oil Consumption, 1989
(quadrillion Btus (Quads))



• Other includes hydroelectric, nuclear, geothermal, and wind power generation and other renewable energy sources.

SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990).

part of an internationally coordinated release of reserves to cushion possible supply impacts from the launching of Operation Desert Storm.

Diversified World Oil Production—Sources of world oil production have become substantially more diversified since the 1970s, with the Organization of Petroleum Exporting Countries' (OPEC) share of the world oil market declining from 60 percent in 1979 to approximately 35 percent today. For the next several years, at least, no single country or cohesive group of countries can control as large a share of the world market as was previously possible.

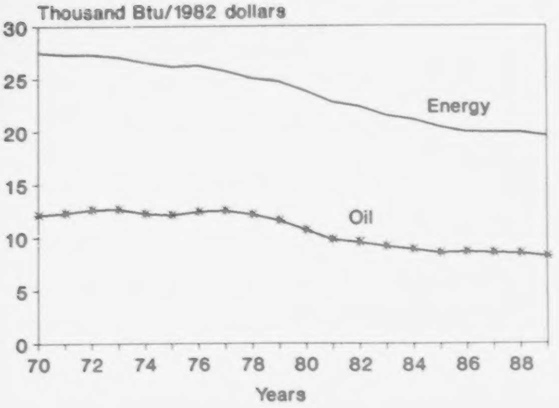
Concentrated World Oil Reserves—Despite diversified world oil production, nearly all recent reserve additions have been in the Middle East. Moreover, the costs of exploration, field development, and production in the Middle East remain considerably below that of other oil-producing regions, and are likely to remain so. As the Soviet Union, the United States, and other non-OPEC nations deplete their oil reserves, the geopolitical importance of Middle Eastern oil will grow.

Increased Flexibility of Oil Use—A significant fraction of any increase in oil consumption, both in the United States and in the remainder of the free world, is reversible. For example, much of the increase in U.S. oil use in transportation over the last decade involves changes in consumer behavior, such as increased driving or purchases of larger cars. Some of these changes could be modified in case of an oil shortage or large price increase. In the industrial and electric utility sectors there has been a shift away from oil to other fuels. At the same time, the fuel switching capability among remaining oil users has grown substantially since the 1970s—allowing many of the existing oil-fired units to burn alternate fuels, primarily natural gas, when price or availability concerns dictate.

New International Oil Trading Mechanisms—Most of the world's oil trade now operates on the spot market, in contrast to the long-term contracts of the 1970s. Coupled with an active futures market, this new oil trading situation makes single-country embargoes, which could never be airtight, even in the past, still less of a threat. Because most contract prices are tied to posted prices on the oil trading exchanges, rapid changes in futures or spot market prices in response to real or perceived threats to oil supplies are almost instantly reflected in the world price of oil.

Increased Availability of Natural Gas—In the 1970s there was widespread concern about the future availability of natural gas. For much of the 1980s the

Figure 1-5—U.S. Energy and Oil Intensity (thousand Btus per 1982 dollar of Gross National Product)



SOURCE: Office of Technology Assessment,1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990).

U.S. natural gas industry has faced surplus capacity and depressed prices. Nonetheless, long-term concerns about future natural gas deliverability and price still exist.

International Agreements on Oil Sharing—The International Energy Agency (IEA) was created in the 1970s in part to coordinate maintenance of strategic stocks of petroleum as well as to coordinate plans for demand reduction for use during an emergency. Since the 1970s the IEA's coordination plans have developed substantially. Additional countries (i.e., Finland and France) are currently seeking IEA membership. In early 1991, the IEA governing board voted to draw on 900 million barrels of crude oil reserves (including the SPR) to avert any shortages caused by the war in the Middle East, but little oil was actually withdrawn because supplies proved adequate and prices remained low.

Changed Energy Regulation—U.S. oil prices are no longer regulated like they were during the 1970s. Given a new price increase, the market forces that act to reduce demand and increase supply will be felt in full. In addition, restrictions on the use of oil and natural gas in electric utility boilers and other industrial applications have largely been repealed.

Changed Economic Structure—Over the last decade, the decline in energy intensity (energy consumed per unit of gross domestic product produced) accelerated in response not only to the influence of improvements in energy efficiency, as noted above, but also to the changing patterns of consumer demand, a shifting balance of imports and exports of both energy and nonenergy goods, and the changing market basket of goods produced in the United States. These changes have, as a consequence, reduced the future oil replacement potential in the U.S. economy.[6] Demographic changes, such as the population migration to the Southwest from the Northeast and Midwestern States, have contributed to reduced overall oil intensity. The use of electricity and natural gas to fuel new residential, commercial, and industrial growth in the Southwest is possibly replacing oil used in the Northeast.

Changed Policy Environment—The policy environment within which regulatory and administrative decisions affecting U.S. oil use are made has changed considerably since the mid-1980s. Concerns over physical shortages of oil have given way to concerns over price trends and volatility, the functioning of international markets, and other public policy goals, such as energy security, environmental quality, and international competitiveness.

OVERVIEW OF U.S. OIL REPLACEMENT POTENTIAL

The Persian Gulf crisis, while one of the largest supply disruptions ever, does not match the scale of the disruption assumed in our 1984 and 1991 scenarios. The reduction in crude oil production capacity from Kuwaiti and Iraqi oilfields at the onset of hostilities was about 4.3 MMB/D. But, because of existing underutilized capacity, the loss was quickly and fully offset by surge production in Saudi Arabia and elsewhere. By early 1991, Saudi crude output increased to 8 MMB/D (up from about 5.5 MMB/D before the war).[7] On the other hand, oil production in the Soviet

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[6] OTA addressed this changing structure in detail in U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy*, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

[7] U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly: February 1991*, DOE/EIA-0109(91/02), (Washington, DC: U.S. Government Printing Office, February 1991), p. xix.

Union, the world's largest oil producer, was down 1 MMB/D from a year earlier, and Soviet ability to sustain historical levels of production is now questionable.

On balance, sustained shortfalls in world oil production due to the war or other disruptions are considered by most analysts to be much less likely then they were in the 1970s. Nonetheless, substantial shortfalls are still possible and recent experience has given some indication of the potentially devastating human and economic costs of a major and prolonged oil cutoff. Given the high concentration of the world's oil reserves in the politically unstable Middle East, the growing dependence of the U.S. economy on oil imports, declining domestic production, and the likelihood that the easiest options for reducing U.S. reliance on foreign oil have already been exercised, it is not surprising that there is now a renewed interest in potential benefits and costs of a strategic policy decision to reduce the risks of oil dependence.

Methodology and Assumptions

For this report OTA examined the oil replacement potential from deploying various technologies that are technically and economically feasible for use within the next 5 years. Technical feasibility requires technologies that are commercially available either now or by 1992 that can be manufactured in sufficient quantity and installed within 5 years, and that require no significant changes in industrial mix or consumer lifestyles. Some technologies even offer additional benefits to environmental quality, economic growth, and international competitiveness. To be economically feasible, the technology must be cost-competitive at today's oil prices or at the significantly higher prices expected to prevail in an oil shortage and/or be among the least costly alternatives for replacing oil use in the relevant sector. The technologies that met these criteria were largely the same ones identified in 1984.

The assumptions used in our updated oil disruption scenario, except for the size and onset of the shortfall, are virtually identical to those used in the 1984 report. The major assumptions for the 1991 reassessment are:

1. A cutoff of Persian Gulf exports to world markets and international oil-sharing agreements result in an immediate loss of 5 MMB/D in U.S. oil imports. The disruption begins in 1991 and is expected to last at least 5 years.
2. The SPR and private oil stocks plus other emergency, voluntary, and mandatory conservation efforts cushion the initial impacts of the shortfall. Eventually, however, the oil reserves are drawn down to zero.
3. Oil replacement technologies that meet the criteria of technical and economic feasibility are deployed over 5 years.
4. Investment capital, materials, and technical personnel are available in adequate quantity to support an aggressive oil replacement strategy. Necessary environmental and other permits and licenses are processed expeditiously, but without any lowering of environmental standards.
5. There are no major structural changes in the output mix or behavior of the U.S. economy that could deter the 5-year deployment objective.
6. There are no new special tax or other government financial incentives that favor or inhibit deployment of specific technologies.

Technical Replacement Capability

In the 1984 assessment OTA found that the potential to replace lost oil imports through conservation, efficiency, and fuel switching was about 1 MMB/D in each of the transportation, industry, and residential/commercial sectors and about 0.6 MMB/D in electric utilities, for a total of about 3.6 MMB/D. Table 1-1 shows the oil replacement technologies and potential savings identified in our 1984 report; figure 1-6 shows the rate of deployment of these oil saving technologies. The drawdown of government and private oil reserves and deployment of oil replacement technologies were more than adequate to respond to a major oil import curtailment of 3 MMB/D within 5 years.

In just 7 years, our oil replacement capability has eroded significantly. We found that the effective U.S. technical oil replacement capability has been reduced to about 1.7 to 2.8 MMB/D, owing to a number of changes over the past decade. This finding has important implications for future strategies to reduce oil consumption. Table 1-2 shows the estimated current oil replacement potential of various technologies under the updated oil disruption scenario. Figure 1-7 shows the rate of oil replacement by sector.

Table 1-1—Estimated Oil Replacement Potential, 1984

Sector	Millions of barrels per day after 5 years[a]
Electric utilities:	
Switching to coal and completing new powerplants currently under construction	0.5
Increased use of natural gas	0.1
Subtotal	0.6
Industry:	
Switch to natural gas	0.45
Switch to coal	0.2
Increased efficiency	0.15
Reduced refinery throughput	0.2
Subtotal	1.0
Residential and commercial (heat and hot water in buildings):	
Switch to natural gas	0.45
Switch to electricity	0.4
Increased efficiency and switch to other fuels	0.15
Subtotal	1.0
Transportation:	
Increased efficiency of cars and light trucks	0.7
Increased efficiency in other transportation modes	0.1
Increased production and use of ethanol	0.1
Switch to other alternative transportation modes	0.1
Subtotal	1.0
Total	3.6

[a] Numbers rounded to nearest 0.05 MMB/D.

SOURCE: Office of Technology Assessment, 1991, from U.S. Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Springfield, VA: National Technical Information Service, September 1984), p. 11.

Residential and Commercial Sectors

A vigorous effort to reduce oil use in the residential and commercial sectors by switching to natural gas, electricity, coal, and renewable fuels and by speeding the adoption of efficiency improvement measures could replace almost 1 MMB/D, or about 72 percent of 1989 consumption, within 5 years. This would entail converting over 13.5 million homes and commercial buildings to natural gas or electric heat and hot water systems and converting 88,000 of the larger remaining commercial and residential heat systems to burn coal slurry fuels. Weatherization improvement, and installation or retrofitting of oil furnaces and boilers with more efficient units in the remaining oil dependent buildings would also contribute to total potential oil savings.

Table 1-2—Summary of Estimated Oil Replacement Potential, 1991

Sector	Millions of barrels per day after 5 years
Electric utilities:	
Convert/switch to coal	0.36
Switch to natural gas	0.09
Renewable fuels	0.10
Newly completed nuclear plants	0.04
Other new capacity and demand management	0.02
Subtotal	0.60
Industry:	
Switch to natural gas	0.30
Convert/switch to coal, electricity, renewables	0.05
Process changes and increased efficiency	0.10
Reduced refinery throughput	0.36
Subtotal	0.80
Residential and commercial:	
Convert to natural gas	0.50
Convert to coal	0.06
Convert to electricity	0.40
Renewable fuels and efficiency improvements	0.05
Subtotal	1.00
Transportation:	
Increased fuel economy in light-duty vehicles	0.30[a]
Alternative vehicle fuels	
natural gas	0.13
biomass fuels (ethanol)	0.03
Improved traffic management	0.10
Subtotal	0.60
Total replacement potential (all sectors)	2.95
Domestic petroleum supply (decline)	(0.1 - 1.2)
Effective technical replacement potential	1.7 - 2.8

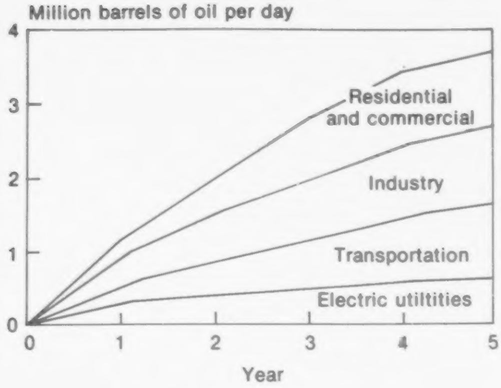
[a] Range of oil savings scenarios 67,000 to 545,000 B/D in 5 years.

SOURCE: Office of Technology Assessment ,1991, based on Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Electric Utility Sector

Electric utilities accounted for less than 5 percent of total oil consumption in 1989. OTA estimates that it is technically feasible to replace about 600,000 B/D, or over 80 percent of 1989 utility oil use within 5 years by fuel switching in existing dual-fuel units, shifting generating loads to non-oil units where capacity permits, completing planned capacity now under construction, converting existing units to natural gas or coal, and installing new non-oil generating capacity, including renewable energy facilities. Power purchases from independent generators and qualified facilities would also contribute to this strategy. These efforts could be facilitated by and additional savings could be gained through demand-side efforts.

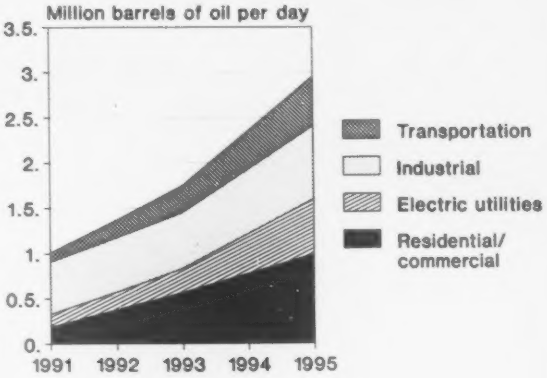
Figure 1-6—Oil Replacement Potential by Sector, 1984



Potential Replacement of Oil Through Fuel Switching and Increased Efficiency.

SOURCE: U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Springfield, VA: National Technical Information Service, September 1984), p. 10.

Figure 1-7—U.S. Oil Replacement Potential Technical Capability by Sector, 1991



SOURCE: Office of Technology Assessment 1991.

Industrial Sector

OTA estimates that the industrial sector could technically displace about 800,000 B/D of petroleum products, or about 20 percent of its 1989 consumption. The oil replacement options in the industrial sector include credit for oil savings from reduced refinery throughput (360,000 B/D) and the savings that would result from switching to natural gas and other fuels for process heat, steam, and power generation, and from intensifying the adoption of a myriad of more energy-efficient process changes in manufacturing (including increased recycling, waste reduction, and use of alternative feedstocks). The major oil replacement potential in the industrial sector is in manufacturing. There still remains only limited capability for replacing oil used in industrial feedstocks and in nonmanufacturing applications in agriculture, forestry, fishing, mining, construction, and oil and gas production.

Our analysis suggests that U.S. flexibility in replacing oil in the industrial sector has declined by about 340,000 B/D since 1984 (exclusive of net savings from reduced refinery throughput). This decline partly reflects a greater reliance on natural gas, electricity, and waste/byproduct fuels and already achieved efficiencies in oil use. However, these savings are offset by rising oil demand for refinery operations and for feedstocks.

Transportation Sector

The transportation sector is the U.S. economy's largest oil user, accounting for almost 63 percent of the Nation's total oil consumption, or about 10.8 MMB/D of petroleum products in 1989—more than domestic oil production.[8] The transportation system is virtually locked into petroleum use for all but the long-term, and efforts to shift to alternate energy sources face significant hurdles. Transportation's share of total oil use has increased from 54 percent in 1979 to 63 percent in 1989, and transportation demand is growing. As transportation uses make up an even larger share of domestic energy use, U.S. flexibility to respond to oil supply and price disruptions will diminish.

The most promising opportunities for fuel savings in both the short- and long-term in this sector involve oil replacement options for automobiles and light trucks, which together account for well over half of transport oil use. Although we can expect continued incremental improvements in fuel efficiency in other motor vehicles and other modes of transportation, the short-term technical potential for reducing petroleum consumption there is relatively small, and no net savings are included in our estimates.

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[8] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 62.

The major oil displacement opportunities for light-duty vehicles (LDVs) for most of the 1990s are improved fuel efficiency, conversion of some fleet vehicles to natural gas and other alternate fuels, and better traffic management. OTA estimates that it is possible to displace about 555,000 B/D of petroleum products in the transportation sector within 5 years, or about 5 percent of 1989 consumption. This would be accomplished using existing technologies and with only minor shifts in customer preference or new-vehicle fleet mix. Additional savings are possible with considerable effort, but would require changes in vehicle manufacturers' product plans, and consumer preference and behavior.[9]

The estimated savings are highly contingent on assumptions about the characteristics of the existing fleet and future changes. For purposes of this report, we have assumed that, under the pressure of a prolonged world oil shortfall, it is technically feasible with available technology to achieve a new LDV fuel economy average of 30 to 33 miles per gallon (mpg) by 1995. This further assumes changes in customer purchase behavior equivalent to the 1987 new fleet size and performance mix. The total oil savings potential after 5 years range from 67,000 to 545,000 B/D, depending on other assumptions about the speed of technology adoption, new car sales, fleet replacement rates, and miles driven. We have adopted a mid-range estimate of 300,000 B/D as a reasonable estimate of potential savings.

The potential saving of about 300,000 B/D from improved LDV fuel economy is significantly less than the 1984 OTA estimate of 700,000 to 800,000 B/D.[10] The 1984 study assumed that in a crisis, the new-car fuel efficiency could be increased from 27.5 to 36 mpg, or a gain of about 31 percent and that these newer vehicles would replace 10-year-old cars that averaged about 14 mpg. Today, the older cars being replaced are more fuel-efficient, and new car fuel-efficiency gains have lagged.

Other measures adopted in response to an oil supply crisis would supply the remaining 250,000 B/D in oil replacement potential, including:

1. converting 1.2 million existing fleet vehicles (about 10 percent of the fleet LDVs) to run on natural gas. (about 130,000 B/D of oil);
2. increasing use of ethanol and expanding production capacity to displace an additional 25,000 B/D of gasoline; and
3. adopting various measures to improve traffic management to promote more efficient vehicle travel, cut vehicle miles traveled, and increase car pooling and reliance on public transportation —together, saving a minimum of 100,000 B/D.

Domestic Oil and Gas Production

Declining domestic crude oil production threatens to exacerbate any oil import shortfall. While crisis-driven increased oil prices and demand for natural gas are expected to spur domestic oil and gas exploration, development, and production, it is uncertain whether, over a 5-year period, these efforts would be able to reverse the rate of decline that could cause domestic oil production to fall to 8 to 9 MMB/D by 1995 from 1989 levels of 9.2 MMB/D. There is some potential for stemming this trend. Production from already discovered onshore and offshore fields, including increased infill drilling, delaying abandonment of existing wells, reopening shutin production, and accelerating enhanced oil recovery, could contribute, by our conservative estimates, from about 170,000 to 510,000 B/D of additional crude oil supply. Expanded natural gas production could also add 100,000 to 200,000 B/D of natural gas plant liquids. But the expected decline in U.S. crude oil production could mean a loss of 400,000 to 1 million B/D resulting in an internal shortfall of 0.1 to 1.2 MMB/D in addition to a 5 MMB/D loss of imports.

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[9] According to a 1988 OTA contractor analysis, a new car fleet average of 38 to 39 mpg would be attainable by 1995, if there were a shift in consumer preferences toward smaller, more efficient models, and if manufacturers accelerated the use of available fuel-saving technologies to more models. With little improvement in fuel economy of the fleet since then, achieving these levels by 1995 would be extremely difficult even under crisis conditions. OTA has examined the potential contributions of various fuel economy standards as part of a separate report, *Improving Automobile Fuel Economy: New Standards, New Approaches*, expected to be published in October 1991.

[10] *The Oil Replacement Capability*, supra note 1.

IMPLICATIONS OF GROWING OIL IMPORT DEPENDENCE AND ERODING OIL REPLACEMENT CAPABILITY

As the United States faces the 1990s and the dawning of a new century, it is more dependent on oil imports and less prepared to respond to a severe oil supply disruption than it was just 7 years ago. Part of this change is the byproduct of our success at replacing many uses of oil and improving our efficiency of use in all sectors. This shift has reduced our easier opportunities for switching from oil in the event of a crisis. And, it has focused attention on two sectors where oil replacement poses significant technical challenges—transportation and industry. Nevertheless, OTA believes that opportunities remain to reduce oil import vulnerability.

It is important to distinguish between *oil import dependence* and *import vulnerability*. Import dependence is measured as the percent of domestic consumption that is met by foreign oil. In 1990 the United States obtained about 42 percent of its oil needs from foreign sources. This was still lower than the high of 46 percent in 1977.[11] A growing level of imports contributes to import vulnerability, but import dependence alone does not translate into a serious threat to energy security. Import vulnerability arises out of the degree and nature of import dependence, the potential harm to the economic and social welfare from a severe disruption in physical supplies or prices, its duration, and the likelihood of such a disruption occurring. Understanding the components of import vulnerability allows the targeting of effective countermeasures.

Because oil use is pervasive and deeply rooted in America's economy and way of life, U.S. dependence on oil imports is of increasing concern. For many, oil is a vital necessity. It heats homes, offices, and schools, provides electricity, and fuels the automobiles, trucks, and buses that move people and things within and among communities. Major and prolonged supply (or price) disruptions would bring hardship and deprivation. Historically, even small supply disruptions have triggered disproportionate economic impacts.

The National Petroleum Council estimated that the 1973 Arab Oil Embargo resulted in a reduction in real GNP of 2.7 percent and that the 1979 Iranian Revolution triggered a 3.6 percent drop in real GNP.[12] Some analysts have estimated that the price impacts of the Iraqi invasion accelerated the recession and added billions to the U.S. oil bill. These disruptions were far smaller than the scenario used in this report.

Future oil disruptions will continue to pose a serious threat to U.S. economic activity even though U.S. reliance upon oil to power its economy and the portion of GNP needed to pay for oil have declined over the last two decades. The growing dependence on imported oil, especially from the politically unsettled Persian Gulf is more cause for concern for several reasons:

1. Greater reliance on oil from foreign sources magnifies the potential impacts of import curtailments on U.S. oil supplies and the economy.
2. Oil imports contribute to U.S. balance of payments deficits and as oil imports (and/or prices) rise, more U.S. export earnings must be allocated to paying for oil rather than devoted to domestic consumption. In 1990 the bill for oil imports amounted to $65 billion, more than half of our $101 billion balance of payments deficit.
3. The threat of potential economic and social dislocations that could accompany major oil supply or price disruptions could constrain U.S. policymakers in foreign affairs, national security and military matters where oil supplies might be affected.
4. The ready availability of cheap imported oil in the United States is a powerful financial disincentive for oil-saving investments in efficiency and alternative energy sources or the development of higher cost domestic oil. Unlike Japan and most Western European countries that are highly dependent on oil imports and where oil is heavily taxed, U.S. oil prices are comparatively low and do not fully reflect many of the external costs of oil use. Among the most notable of these externalities are, for example, the environmental damage from production, oil spills, and emissions from refining and combustion, and the costs of maintaining and

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[11] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review: July 1991*, DOE/EIA-0035(91/07) (Washington, DC: U.S. Government Printing Office, July 1991), tables 3.1a and 3.1b.

[12] National Petroleum Council, *Factors Affecting U.S. Oil and Gas Outlook 1987*, Washington, DC, 1987.

deploying military forces to protect supplies). The defense costs in particular have applied disproportionately to the United States relative to European countries and Japan.

Some argue forcefully that increased import dependence should not be viewed as a threat as long as the net domestic economic benefits are positive. Low oil prices have been advantageous for many American businesses and consumers, but have undercut domestic oil ventures, energy efficiency initiatives, and competing alternative energy sources. An honest appraisal of the costs and benefits must take account of all the social, economic, environmental, and political costs of increased import reliance and of the availability of measures to counter the risk it entails.

Of course, if it is less expensive (as measured in total indirect and direct costs) to import oil than to offset that need domestically, then it makes sense to import. But there is strong reason to believe that the reverse is true, and that our national economic well-being would be improved by shifting investment to limit imports under a long-term least-cost strategy.

MAJOR OPPORTUNITIES FOR REDUCING OIL IMPORT DEPENDENCE

Historically, since the early 1970s, the biggest oil savings in the U.S. economy have come from fuel switching in electric utilities, industry, and the residential and commercial sectors and from efficiency improvements in all sectors. The transportation sector still offers attractive options for oil savings by improving the fuel economy of automobiles and trucks, reducing total driving in the United States, and switching to alternative transportation fuels. In addition, increasing the diversity in world oil production reduces the vulnerability of U.S. oil use to political instability in specific oil supply regions, notably the Middle East.

Because transportation accounts for 63 percent of total U.S. oil use (about 10.8 MMB/D, up 17.6 percent from 1983), it offers the largest potential opportunities for oil savings. And some progress has been made: average automobile fuel efficiency is up—from about 17 mpg in 1983 to about 20 mpg in 1988. (Average *new* car efficiency has increased, from 26 to 28 mpg.) However, the average number of miles driven per car and the number of cars are also up sharply. The net result is that motor gasoline consumption has been gradually increasing since 1983, from 6.6 to 7.3 MMB/D in 1989. Substantial opportunities thus remain for improving the fuel efficiency of U.S. cars and trucks.[13]

In addition to cutting oil use, improved automotive fuel economy has other recognized benefits. Since 1983 the policy initiatives for pursuing improved auto fuel economy have expanded beyond the traditional (and now resurgent) concern over energy security to include local and global environmental concerns as well (urban ozone, acid rain, and global warming issues). The environmental dimension strengthens but complicates the likely policy options, since the persistent controversies over the technical potential of improved fuel economy and the relationship between fuel economy and pollution emissions continue. Environmental concerns have, however, improved the longer term prospects considerably for shifting from gasoline to alternative transportation fuels—alcohol-based fuels, natural gas, electricity, or hydrogen.[14]

The situation is further complicated by recent market demands for increased performance at the expense of fuel economy, probably brought about by low real fuel prices (gasoline prices today in 1991 are lower in real terms, i.e., adjusted for inflation, than in the 1970s). Moreover, average new car prices in real terms increased almost 50 percent in the decade 1978 to 1988, contributing to the trend of a longer average age of cars on the road (up from 6 to 7.6 years during that same decade). As a result, an important opportunity may lie in providing incentives to get older, less efficient vehicles off the road.[15]

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[13] OTA examined U.S. automotive fuel economy improvements as part of a related OTA report, *Improving Automobile Fuel Economy: New Standards, New Approaches,* to be published in October 1991. Interim results were offered in Steven E. Plotkin, Senior Associate, U.S. Congress, Office of Technology Assessment, "Legislative Proposals to Increase Automotive Fuel Economy and Promote Alternative Transportation Fuels," testimony before the Subcommittee on Energy and Power of the House Committee on Energy and Commerce, Apr. 17, 1991.

[14] See U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels For Light-Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

[15] OTA is investigating the costs and benefits of retiring older vehicles in it's ongoing project, *Retirement of Older Vehicles: Fuel Efficiency and Emissions Reduction Benefits.*

In U.S. industry, many of the energy efficiency investments of the 1970s, the fuel switching to natural gas and electricity, and the changing market basket of goods and services produced in the United States have contributed to the declining oil intensity since 1983 (see figure 1-5).[16] Much of the fuel switching has resulted from the large increase in the use of dual-fuel boilers (oil and natural gas) since the early 1980s. Many of these boilers now burn natural gas because of the favorably low prices of natural gas relative to oil that existed even before the current oil price rise.[17]

By 1983 many of the opportunities to reduce oil consumption in the electric power sector had already been exploited in response to the 1973 and 1979 oil price shocks, and so today few utilities are very dependent on oil (although until the recent crisis, a number of them were reconsidering oil as an option, given the 1986 price drop). Nonetheless, the United States still consumes slightly more oil today in electric power generation than it did in 1983—740,000 B/D in 1989 versus 673,000 B/D in 1983. The bulk of this generation is located in New England, New York, the Middle Atlantic States, California, and Hawaii. However, many utilities now use oil primarily to generate electricity only at peak times, rather than as a base or intermediate generating option. In addition, utilities have many other generating options (including natural gas), more aggressive demand-side management, and purchases from nonutility generators (either independent power producers or qualifying facilities under the Public Utilities Regulatory Policies Act, Public Law 95-615).

Finally, residential and commercial use of heating oil is currently about 1.4 MMB/D, although it has been increasing since 1983 (about 9 percent). Twelve percent of U.S. households use heating oil as the primary fuel, down very slightly from 1983. Much of this consumption is in New England and the Middle Atlantic States where electricity rates are high and natural gas availability limited. Most areas do have alternatives available to shift from oil to natural gas or electricity. More concerted oil conservation measures such as improving building weatherization and furnace efficiency improvements can shave oil use in this sector.

The portfolio of technical options that might be used to implement strategic decisions to reduce oil import dependence are largely the same as those in a disruption scenario, minus the emergency measures for reducing oil use such as rationing or other mandatory restrictions on oil use. The relative long-term effectiveness, and hence the priority of alternative options, may be different in a strategic scenario. For example, over a 5-year period, alternative transportation fuels would likely play a minor role, in the longer term they will be essential.

Automotive Fuel Economy

Automobiles and light trucks account for 40 percent of U.S. oil consumption. The efficiency of the new vehicle fleet increased sharply in the 1970s with the advent of higher mileage standards and fuel prices. But gains have ceased in the face of government apathy and consumer preference for increased vehicle acceleration, size, and other characteristics that conflict with improved fuel economy (see figure 1-8).

OTA believes that there is a substantial potential for further fuel economy increases through purely technological means (i.e., without diminishing consumer choice), but the magnitude of this potential within the next decade is not what we would like it to be. Even without the push provided by a severe supply disruption or dramatic increases in gasoline prices, technology is available that would allow a new car fleet fuel economy of about 30 mpg by 1995 and 37 mpg by 2001 (both values measured according to the Environmental Protection Agency's test procedure).[18] Longer term progress, beyond the year 2000, could be much larger if strong, continual incentives for fuel economy are brought to bear on the industry. Regulatory or other measures that produce a basic shift in the size and performance of the fleet could stimulate even

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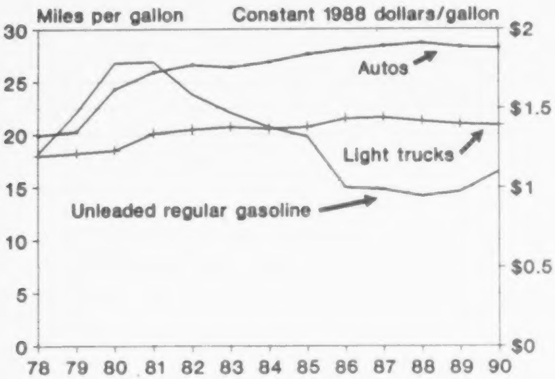
[16] See U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy,* OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

[17] The efficiency of energy use in industry is being explored in OTA ongoing assessment, *U.S. Energy Efficiency: Past Trends and Future Opportunities.*

[18] These values assume that each manufacturer is required to meet a company-specific standard that reflects its particular technological capability. By using all technologies identifiable today as likely to be achievable for 2001 model year regardless of cost, and assuming a rollback to 1987 size and performance, we believe that the entire U.S. fleet could achieve 38 to 39 mpg. OTA is currently completing an analysis of automotive fuel economy at the request of the Senate Energy and Natural Resources Committee.

Figure 1-8—Estimated Car and Light-Truck New Fuel Economy and Gasoline Prices, 1978-90



SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: May 1990); and Stacy C. Davis and Patricia S. Hu, *Transportation Energy Data Book: Edition 11*, ORNL-6649 (Edition 11 of ORNL-5198) (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991), tables 2.19 and 3.33.

greater gains in overall fuel economy than what can be achieved with strictly technical fixes. For example, the options for improving automotive fuel economy in OTA's study on global climate change,[19] included scenarios that permitted altering the mix of vehicle size and weight for the U.S. fleet as well as introducing technical improvements aggressively, including a shift to diesel engines. Under such assumptions, new car fleet efficiencies of 42 mpg by 2000 and 58 mpg by 2010 might be achievable.

Today's light-duty passenger vehicles include automobiles, minivans, vans, and light trucks. Vans and light trucks have lower fuel economy standards than passenger cars and are a large and increasing portion of the U.S. fleet. To achieve higher fuel economy goals all passenger vehicles will have to be targeted. Table 1-3 shows a summary of OTA's analysis of the various conditions under which improved automotive fuel economy would be possible in the short term.

Table 1-3—OTA Estimates of Potential Short-Term Fuel Economy Gains (EPA miles per gallon)

1995 Product plan

Assumptions:

- Manufacturers' currently planned product line with fuel economy technologies "cost effective" at low oil prices
- Continuation of current trends in size and performance mix of new cars
- No new policy initiatives

Potential automotive fuel economy:

28.3 miles per gallon (mpg) domestic
31.1 mpg imports
29.2 mpg fleet

1995 Product Plan - Short-Term Fuel Economy Gain

Assumptions:

- Manufacturers' current and planned product line with a return to overall relative size, weight, and performance mix of 1987 new cars
- Existing (low oil price) cost effective fuel economy technology
- Customer preference for more fuel efficient version of each model

Potential automotive fuel economy:

31.2 mpg domestic
34.6 mpg imports
32.3 mpg fleet

SOURCE: Office of Technology Assessment 1991.

Alternative Transportation Fuels

The growth of non-oil based liquid fuels is an important adjunct to increased fuel economy and increased domestic oil production (in reducing U.S. dependence on imported oil). A recent OTA analysis of several alternatives to gasoline[20] found that alternative fuels present a key opportunity to reduce U.S. oil dependence. Over the next few decades, alternative fuels derived from natural gas—methanol and compressed natural gas (CNG)—and from biomass, including truly renewable fuels from sustainable production of biomass, should be capable of substituting for a significant fraction of transportation petroleum use.

Electric vehicles, perhaps employing not only batteries, but fuel cells or small engines, could also be important possibilities in some regions of the United

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[19] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991).

[20] U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternatives for Light-Duty Vehicles*, OTA-E-364 (U.S. Government Printing Office, October 1990).

States in the later 1990s. This, of course, depends on the pace of research and technology development in energy storage technology and the constraints on other options. For example, last year California passed legislation requiring deployment of some "ultra-low polluting" vehicles to promote air quality, and other States are considering following California's lead.

Currently, coal-based liquid fuels are considerably more expensive than natural gas-based fuels. However, continued development of the fuel production processes have lowered costs and, in the future, may lower costs sufficiently that this source could compete economically with fuels from natural gas. Large U.S. coal reserves make coal-based liquid fuels attractive from an energy security perspective. But, even with emerging "clean coal" technologies, coal use presents serious environmental challenges (especially carbon dioxide emissions), that the Nation cannot afford to ignore in evaluating which potential liquid fuel strategies to pursue.

As an even longer term option, the transportation sector might free itself from fossil fuel dependence by tapping electricity and hydrogen, both obtainable from nuclear and solar sources. But both have serious cost, engineering, and other constraints and will require a major development effort. Over the next century, however, they could greatly diminish greenhouse gas emissions by progressively replacing fossil-based transportation fuels.

Increased Domestic Production

The recent decline in U.S. oil production could be slowed somewhat if rising oil prices stimulate increased production from existing fields and accelerated use of enhanced oil recovery technologies.[21] Compared to other oil-producing regions, the United States has been extensively explored. Experts estimate that 80 percent of the oil and gas eventually to be found in the United States lies in fields that have already been discovered.[22] The remaining exploratory potential is still substantial. But much of this undiscovered oil and gas will come from smaller fields than in the past.

This maturity does not mean that the future for the U.S. oil industry is a rapid and inevitable decline in production from increasingly high-cost deposits. Many in the oil industry hold to a belief that domestic production can be stabilized or slightly increased. In support they note the continuing strength in U.S. reserves additions and a more sophisticated understanding of the nature of U.S. oil and gas resources.

Even as drilling activity has slowed, reserve additions since 1986 have averaged 90 percent of those in the high oil price-high activity years 1978 to 1985. An estimated 86 percent of these reserve additions are attributable to reserve growth in existing fields—i.e., increases in the estimates of conventionally recoverable oil resulting from extensive and intensive drilling within existing fields, improved recovery, and identification of new pools.[23]

The past decade has brought recognition that sizable quantities of conventionally mobile oil remain to be recovered in existing fields. The greatest potential recovery is contained in complex reservoirs that will require improved geologic models to make infield drilling and enhanced oil recovery more effective in tapping these deposits. Enhanced oil recovery techniques are evolving that eventually could allow production of the immobile, residual oil in existing reservoirs.

Tapping these resources is contingent on the economic attractiveness of the prospects at present and anticipated world oil prices, and continued technology development. The higher oil prices and sense of urgency accompanying a severe oil import disruption would likely provide some impetus for expanded exploration and development.

Oil exploration activities are a primary key to maintaining reserve additions to sustain production. Exploration activities surged in the late 1970s because of high oil prices and the expectation that even higher world oil prices would prevail. In 1981, as a result of this rapid industry expansion, the main indicators of exploratory activity reached record peaks—a weekly average of 3,970 rotary rigs operating, a monthly average of 681 seismic crews active, and an annual total of over 17,500 exploratory wells completed.[24] When world oil prices began to slide, domestic exploration activities fell too. The free fall in world oil prices in 1986 further devastated domestic exploration and development. That year the number of wells drilled plunged to 201, and rotary rigs active totaled only 964—less than half the number operating a year before.[25] Exploratory wells completed dropped to 7,150. As oil prices began to firm up in the later 1980s, albeit at much lower real levels than previously, there was a modest rise in domestic exploration and development investment. However, key indicators still hit a 40-year low in 1989—869 rotary rigs in operation, 132 seismic crews active, and about 5,220 exploratory wells completed.

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[21] See *U.S. Oil Production: The Effect of Low Prices*, supra note 3.

[22] W.L. Fisher, "Factors in Realizing Future Supply Potential of Domestic Oil and Natural Gas," paper presented to the Aspen Institute Energy Policy Forum, July 10-14, 1991, Aspen Colorado.

[23] Ibid.

This sustained drop in exploration and production activity resulted in a shrinking in the infrastructure of the domestic oil industry. The reduction in the availability of equipment, skilled workers, and supporting manufacturing and maintenance services capability could slow any future expansion of domestic exploration.

The higher oil prices in 1990 brought about a brief upswing in exploration indicators, but by late spring 1991, these critical indicators were again trending downward as lower world oil prices returned and domestic natural gas prices all but collapsed.[26] Even so, for the first time since 1985 domestic crude oil production increased—up 0.6 percent over the first 6 months of 1990. The rise was attributed to better economic conditions for producers, the expanded exploration and development activities in 1990, and improved technology.[27]

The scarcity of new opportunities for finding large new oil fields within the mature oil regions of the lower 48 States has created pressure for the Federal Government to open to exploratory drilling and development a number of promising areas currently off-limits to such activities, such as the Arctic National Wildlife Refuge (ANWR), offshore California, and other frontier areas.

The debate over ANWR development is a classic battle between conservation and resource development interests.[28] The oil industry considers the coastal plain of the ANWR to be the United States' most promising remaining prospect for finding giant oil fields, and they have made it the central focus of the debate for opening new areas for commercial exploitation. There is considerable disagreement, even among proponents, about how much commercially recoverable oil might be present in the refuge, if any.[29] Earlier in 1991, the Department of the Interior released a revised estimate that ANWR has a 46-percent chance of containing economically recoverable oil, with a mean estimated oil volume of 3.6 billion barrels—a potential resource equivalent to the third largest discovery in U.S. territory and one that, for a few decades, could deliver several hundred thousand barrels of crude oil per day to the lower 48 States.[30]

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[24] *Annual Energy Review 1989,* supra note 8, tables 41 and 42.

[25] For further discussion of the impacts on the domestic petroleum industry, see *U.S. Oil Production: The Effect of Low Oil Prices,* supra note 3.

[26] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review: June 1991,* DOE/EIA-0035(91/06) (Washington, DC: U.S. Government Printing Office, June 1991); and Institute of Gas Technology, *International Gas Technology Highlights,* vol. 21, July 15, 1991.

[27] See "Oil Demand Falls to Lowest Level Since 1983," *The Energy Daily,* July 18, 1991, p. 4.

[28] See *Oil Production in The Arctic National Wildlife Refuge: The Technology and the Alaskan Oil Context,* supra note 3.

[29] See the discussion of the factors and assumptions that drive various estimates of ANWR potential in *Oil Production in the Arctic National Wildlife Refuge,* supra note 3. ch.3

[30] OTA has reviewed the Department's previously published estimates of a 19 percent chance of at least one field with commercially recoverable quantities of oil with an estimated mean of 3.2 billion barrels of recoverable oil. We found that this estimate was highly sensitive to their assumptions about the minimum economic field size—i.e., the smallest oilfield that could support the oil pipelines and other facilities needed to produce and move the oil. This minimum field size is, in turn, dependent on oil price. DOI had assumed a world oil price in the year 2000 of $35/bbl oil price in 1984 dollars, which has been criticized as to high. Lowering the assumed price would increase the minimum economic field size required and reduce the estimated probability of finding commercial quantities of oil in the ANWR, and affect estimates of the volume of recoverable oil. OTA's review found that DOI's minimum economic field size was probably too large, because smaller fields could likely be developed at the assumed price, or larger fields at a lower price. Overall, because DOI's estimates were based on assessments of both geologic and economic factors, OTA could not conclude that DOI's estimate of total recoverable oil resources in ANWR coastal plain were either conservative or optimistic. Some factors tend to understate estimates of ANWR potential, while others could overstate it. OTA did conclude, however, that DOI's estimate of a 19 percent probability of finding economically recoverable oil in the refuge was probably overly pessimistic. Ibid., pp. 103-105. According to reports, the 1991 revised DOI estimate reflects some additional geologic data, and modifications in some of the economic assumptions, but specific details were not published.

Groups opposing development view the coastal plain as a unique and invaluable Arctic ecosystem and wilderness area, and are convinced that exploration poses unacceptable risks, and that development would destroy the plain's wilderness character and seriously damage its wildlife and other environmental values. They also point out that relatively modest investments in energy efficiency could save a similar amount of oil over the same period of time.

Even if Congress were to act swiftly to authorize exploration of the coastal plain of the refuge with an accelerated leasing schedule, and if the industry were to discover oil and move as rapidly as possible to develop the field, oil could not start flowing from the plain for many years. The industry's own estimates of the time from actual leasing of the plain (which itself will take a few years) to production startup is about 12 years, and peak production would not be reached for a number of years after that. Estimates for new production leadtimes from frontier offshore areas are similar. Given the long periods involved, such prospects are more important as potential components of longer-term energy plans than as part of any near term response to an actual or threatened loss of oil imports—and as longer-term options they can be evaluated according to overall goals of energy security, environmental quality, and prosperity.

For the nearer term, the best hopes for maintaining domestic production lie in the same nonglamorous sources that have continued to supply most of the reserve additions in recent years. These include sustaining exploratory and developmental drilling activity in known fields, horizontal drilling, accelerating enhanced oil recovery, bringing shutin or marginal oil fields back into production, and limiting the premature abandonment of existing wells.

Diversity in Oil Supply

The world's recoverable world oil resource is huge, but much of it is in the Middle East. Moreover, as demand for oil grows in rapidly industrializing nations, it is not safe to presume that in the future the United States can count indefinitely on 8 to 10 MMB/D in oil imports at an attractive price. The United States could ease pressure on world oil supplies by encouraging oil exploration and development in areas outside of the Middle East. For example, helping the Soviets expand oil production in return for a share of it could have several benefits to the United States. Because the region has major sedimentary basins with limited exploration and poor production to date, success in developing this region and in increasing Soviet oil exports would not only diversify the U.S. import base but also provide the Soviets with the hard currency so badly needed to maintain peaceful progress toward a viable market economy. A second example is the opportunity (again with joint ventures in research, exploration, and production) to assist sister nations in the Western Hemisphere in petroleum development. Massive reserves, for example, exist in Venezuela, some of which (e.g., the heavy oils in the Orinoco Basin) can benefit from further research.

LOOKING TOWARD THE FUTURE—SCENARIOS FOR REDUCING OIL DEPENDENCE

What would be the relative contribution of these various options in possible future scenarios for reducing U.S. oil import dependence? Figures 1-9 through 1-11 summarize the impacts of several aggressive strategies for reducing U.S. oil import dependence. The scenarios focus on the options of increased supply, efficiency, and fuel switching. The major strategies include improving automotive fuel economy, increasing domestic oil production, expanding use of alternative fuels in transportation, and switching away from oil and enhancing end-use efficiency in the industrial, residential, and commercial sectors.

The three alternative future scenarios were derived by OTA from the Energy Information Administration's (EIA) *Annual Energy Outlook 1990* Base Case.[31] As the figures clearly indicate, vigorous and sustained efforts would be required to hold down oil import dependence over the next several decades—even to a level of 50 percent of total consumption.

Scenario I: Baseline—Figure 1-9 is a baseline adapted by OTA from the EIA *Annual Energy Outlook 1990* Base Case. With some adjustments, the Baseline represents a continuation of current trends

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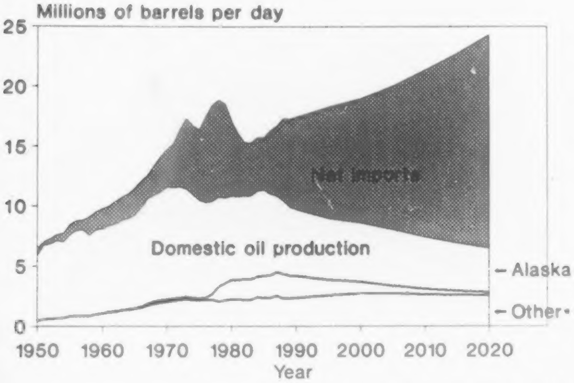
[31] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1990 With Projections to 2010,* DOE/EIA-0383 (Washington, DC: U.S. Government Printing Office, January 1990).

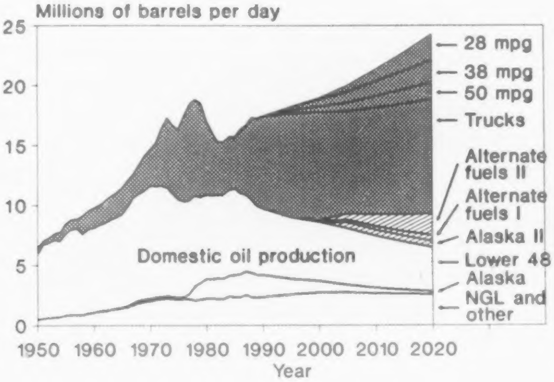
Figure 1-9—U.S. Oil Supply and Demand Futures Baseline Projection: Current Trends in Domestic Oil Production, Net Imports, and 1989 New Car Fuel Economy



*Natural gas liquids and other

SOURCE: Office of Technology Assessment 1991

Figure 1-10—U.S. Oil Supply and Demand Futures: Impacts of Increased Domestic Oil Supply and Improved Fuel Economy



SOURCE: Office of Technology Assessment 1991.

without additional energy efficiency and oil import displacement initiatives. The Baseline values for oil production from Alaska and the lower 48 States extend the 2005 to 2010 trend projected by the EIA to 2020. Natural gas liquids (NGL) production was similarly left at the EIA projected levels to 2010, and then extended to 2020 following the same trend as 2005 to 2010. The category "Other" (e.g., miscellaneous refinery products) was frozen at the EIA 1995 level of 0.8 MMB/D; levels in the EIA projection above 0.8 MMB/D were separated under the category "Alternative Fuels I" and were added in separately in scenarios II and III.

The EIA projection assumes U.S. new vehicle fuel economy reaches 38 mpg for new cars and 24.4 mpg for new light trucks in 2010. Our base case (figure 1-9) adjusted the EIA projection to reflect a continuation of the current level for new cars of 28 mpg and for new light trucks of about 21 mpg.[32]

Scenario II: New Supply and Efficiency Improvements—Figure 1-10 illustrates the impacts of three new sources of liquid fuel supplies and three levels of transportation efficiency improvements phased in gradually.

The line labeled "Alternative Fuels I" assumes that fuels such as methanol, ethanol, and the like are added beginning in 2000 and reach a consumption level of 500,000 B/D by 2020, with production capacity increasing by 100,000 B/D every 5 years.[33] The line labeled "Alternative Fuels II" reflects the accelerated development of alternative biomass-derived liquid fuels resulting from intensive investment in renewable energy research, development and demonstration activities.[34] The line labeled "Alaska II" assumes that a large new oil field is found in Alaska and an accelerated development effort is results in production beginning in 2000 and rising to 500,000 B/D by the year 2005.

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[32] This adjustment resulted in a change in weighted (cars and light trucks) fleet average mileage from EIA projected levels of 23.5 mpg in 2010 to 20.5 mpg in 2000, which was then kept at this level till 2020 (on-the-road mileage is assumed to be 80 percent of that measured by a CAFE-type standard). Corresponding annual percentage changes in mileage (on-road fuel economy of the total fleet) are 1.18 percent in the EIA projection (38 mpg case) carried through to 2020, and 1.0 percent in the 28 mpg case until 2000 and then left unchanged from 2000 to 2020. This assumed increase in light-duty vehicle fuel economy is counterbalanced, however, by EIA projections of an increase in vehicle miles traveled (VMT) of 1.82 percent per year from 1988 levels through 2010. We assumed that VMT continue to increase at this rate through 2020 driven by such factors as population growth of 0.8 percent/year (246 million in 1988 to 307 million in 2025) and real GNP growth of 2.4 percent per year overall, or about 1.6 percent per year per capita.

[33] These estimates are derived from the EIA Base Case, Ibid., and are comparable to the estimates used in the development of the President's National Energy Strategy. See the "Business as Usual" case in "The Potential of Renewable Energy: An Interlaboratory White Paper," SERI/TP-260-3674 (Golden, CO: Solar Energy Research Institute, March 1990).

[34] The accelerated development case listed in the Interlaboratory White Paper, Ibid., foresees alternative biomass derived liquid fuels reaching 1.8 MMB/D more than in the base case by 2020 if additional RD&D funding is made available.

Figure 1-10 also depicts three different transportation efficiency improvement strategies that are assumed to be phased in gradually through the year 2020. These are shown as "28 mpg" (base case), "38 mpg," "50 mpg," and "Trucks." The 28 mpg case is a continuation of the current new car fleet fuel economy average. The 38 mpg case reflects the fuel economy gains assumed in the EIA Base Case. The 50 mpg case assumes that by 2020 both new cars and new light trucks have an overall weighted average fuel efficiency of 50 mpg, resulting in an average on-the-road total fleet fuel efficiency of 36 mpg by 2020 (allowing for turnover of the fleet stock and for the 20-percent reduction in actual on-the-road efficiencies from CAFE-type standards). The case "Trucks" assumes that the use of compressed natural gas and increased efficiency could reduce by half the projected 2020 diesel fuel consumption by heavy trucks, buses, and others heavy vehicles (based on continuing the EIA projection to 2010 at the same growth rate to 2020) could be reduced by year 2020.

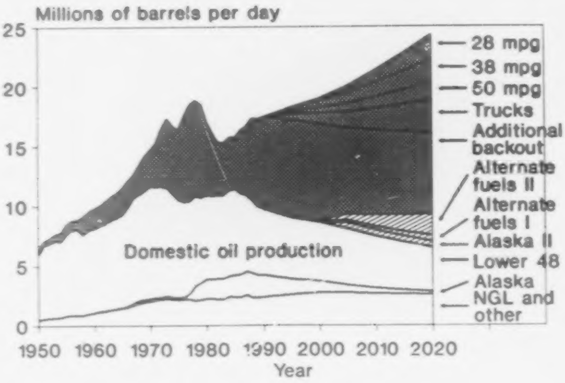
Scenario III: Aggressive Oil Backout—Figure 1-11 includes further oil replacement and conservation initiatives in industry and electric utilities. It assumes (in addition to the 50 mpg light-duty vehicle fuel economy and "Trucks" adopted in Scenario II) that one-half of the remaining nontransport uses of oil will be reduced (backed out) in an aggressive oil conservation and fuel conversion program. This results in a savings of 2.7 MMB/D by 2020, phased in linearly.[35] Compared with current rates of use, this would suggest oil savings in the EIA Base Case of about one-half in the residential and commercial sectors, and one-third in the industrial and utility sectors from what it would be in 2010 if energy use were to grow linearly with economic activity and population.

The lesson from these scenarios is that much can be done to countervail against the ominous projected growth of oil import dependence, but that even with relatively heroic measures we face a future of high dependence on imports.

POLICY CONSIDERATIONS

The United States has already taken a number of steps to offset import vulnerability, such as establishing (and using) the SPR, adopting CAFE standards, and supporting oil replacement and efficiency technology research development, and demonstration (RD&D). Should Congress decide to take further action targeted at reducing oil vulnerability, there are a number of potentially effective measures available. No single technology will eliminate oil import dependence and there are no quick fixes to the oil import vulnerability dilemma. Any significant shift away from oil products cannot be accomplished quickly and may entail substantial capital investment and adjustments in consumer preferences and lifestyles. An effective approach will require a combination of oil replacement initiatives, perhaps combined with other energy and environmental policy measures. But no strategy will be successful unless it has the continuing support of goernment, business, and consumers.

Figure 1-11—U.S. Oil Supply and Demand Futures, Impacts of Improved Domestic Oil Supply and Fuel Economy, and Oil Backout



SOURCE: Office of Technology Assessment 1991

This report presents two strategies for promoting the adoption of oil replacement technologies:

1. replacing oil use in a severe import disruption, and
2. reducing oil import vulnerability as part of long-term national energy policy objectives.

Chapter 5 discusses various policy options that might be utilized under each strategy. Both strategies rely on many of the same oil replacement technologies and policy initiatives. One critical difference is that some policy options and technologies have fewer implementation problems and offer greater oil savings if adopted as part of a long-term oil replacement strategy rather than as part of a crisis-driven strategy.

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[35] The EIA Base Case Scenario already envisages annual residential and commercial consumption of oil decreasing at 2.6 percent and 1.8 percent respectively, between 1990 and 2010, while population grows at 0.6 percent and total real GNP grows at 2.4 percent annually. Oil use in the utility and industrial sectors is assumed to increase at about 0.7 percent per year each, while electricity generation and manufacturing output are assumed to increase 3 percent and 2.8 percent, respectively, per year.

Replacing Oil Use in a Severe Import Disruption

The major Federal goals in responding to a severe oil import crisis would be cutting oil use in all sectors, speeding the adoption of oil replacement technologies, encouraging domestic oil and gas production, and easing the negative social and economic impacts of reduced oil supplies. Attaining the maximum technical oil replacement potential will require concerted efforts, large amounts of capital, broad public support, and government leadership. There is a wide range of possible legislative options that could enhance oil replacement in each sector. But because oil replacement technologies alone will not be sufficient to make up the shortfall, it is also relevant to consider the adequacy of Federal energy emergency authorities and plans.

Residential and Commercial Sectors

In an oil emergency, getting residential and commercial building owners to accelerate oil conversions and efficiency improvements in existing buildings will require a mix of information, exhortation, direct financial incentives, and voluntary and mandatory efficiency standards. Successful implementation of an oil replacement strategy will require the cooperation of millions. Legislative options to foster oil savings include: taxes or surcharges on oil products and equipment, measures to reduce front-end-costs and cash flow barriers, financing assistance, efficiency standards, labeling and certification programs, public information, and technology R&D programs. Measures to improve local availability of natural gas would also help oil-to-gas conversions.

Electric Utility Sector

Most oil dependent utilities now appear well situated to respond to an oil supply emergency. Nevertheless, there are several legislative actions that could further enhance oil displacement capability and oversight. Most of these measures would be most beneficial if they were put in place before any oil import emergency. Following the precedent of PURPA, Congress might, for example, require States to consider adopting regulatory policies that favor oil replacement technologies and efficiency improvements in planning, licensing, and rate matters and to prepare oil emergency contingency plans. Congress might also direct the Federal Energy Regulatory Commission (FERC) to defer to State-approved oil replacement plans in passing on the rates, terms and conditions for wholesale electricity transactions. Measures that improve interstate transmission system capability and transmission access for emergency power transfers to displace oil generation or that enhance regional availability of natural gas, would also improve oil replacement capability.

Industrial Sector

Because of the diversity of oil use in the industrial sector and the limited oil replacement alternatives available, targeting of incentives and technical standards is difficult. This sector is highly sensitive to price signals. In an oil emergency, higher oil prices, coupled with concerns over the availability of oil products at any price, would probably trigger a high degree of oil replacement without any additional financial incentives. Targeting financial incentives to spur incremental oil savings and efficiency improvements without creating a windfall for those who would make the investments anyway has proven difficult in the past. OTA previously found that, in general, policies that encourage investment in new plant and equipment also tend to improve energy efficiency, including efficiency of oil use.[36] Programs that improve the availability of information to industrial consumers about potential energy and oil savings have also proved helpful.

Areas for possible legislative action to improve oil replacement capability in this sector include technical assistance, information, and R&D programs to identify and disseminate oil saving industrial technologies and financial incentives such as tax deductions, credits, or loan guarantees specifically targeted at incremental oil savings. Additional RD&D efforts might be directed at developing effective oil replacement technologies for oil-derived feedstocks and for oil products used in nonmanufacturing applications. There also appear to be opportunities for indirect oil savings through actions directed at increased recycling and reduction of hazardous and solid wastes (e.g., recycled plastics, tire-derived fuels). Attention might also be give to the adequacy of Federal emergency authority to restrict oil use or require conversions, private oil stockpiles, and the availability of natural gas supplies and storage for industrial users. With the limited exception of revised and expanded Federal oil emergency authority, all of these measures would work best if put in place in advance of any import crisis.

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[36] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use,* OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983), available through the National Technical Information Service, Springfield, VA 22161, NTIS order #PB 83-240-606.

Transportation Sector

Cutting oil use by cars and light trucks offers the most significant opportunity for short-term oil savings in transportation. An aggressive oil replacement strategy would include four goals:

1. improving light-duty vehicle (LDV) fuel efficiency;
2. accelerating the adoption of alternative non-oil transportation fuels and vehicles;
3. limiting the increase in or cutting vehicle miles traveled; and
4. improving the efficiency of traffic movement.

Achieving the full savings potential will require action by Federal, State, and local governments, cooperation by manufacturers, and a high degree of public acceptance.

Improvements in new LDV fuel efficiency would offer oil savings over 5 years even without changes in fleet mix and consumer preference. Forcing incremental efficiency gains is difficult because of the challenges in modifying manufacturers production plans and consumer purchasing patterns. Policy options for improving LDV fuel efficiency include:

- *Amending Federal vehicle fuel efficiency standards to require new cars and light trucks to attain maximum fuel economy levels under available technology.* The choice of an appropriate standard will require a balancing of many interests and is the subject of a separate OTA study.[37] The level of savings that could be achieved is also dependent on other factors such as the level of new car sales, fleet turnover rates, and consumer preferences.

- *Using various market-oriented mechanisms to affect the front-end and life cycle costs of LDVs, based on the assumption that consumers will choose more efficient vehicles in response to such price signals.* Examples of mechanisms that could be used alone or in combination include imposing significantly higher gasoline taxes, raising the gas guzzler tax on the purchase of inefficient new vehicles, offering gas sipper rebates for highly efficient new vehicles, and imposing fuel efficiency-based annual vehicle registration fees. Past studies on the effects of higher prices on vehicle preferences and discretionary driving are mixed, so that the effectiveness of these measures alone is uncertain. At the very least, they appear to be more effective as longer term, rather than rapid response, measures in affecting overall fleet efficiency.[38]

- *Requiring fleet operators (including Federal agencies) to purchase more fuel-efficient vehicles.* Fleet vehicles on average are driven more than private vehicles, so that efficiency improvements here offer significant savings. Imposing purchase requirements also would tend to create a market-pull for more fuel-efficient vehicles and would prompt manufacturers to supply them. The Federal Government alone is the largest purchaser of LDVs in the country.

Shifting a portion of the LDV fleet to vehicles that run on fuels not derived from oil could offer attractive oil savings within 5 years and even greater savings beyond then. The successful commercialization of alternative fueled vehicles requires:

- manufacture or retrofit of alternative fuel vehicles in sufficient quantity,

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[37] OTA is currently completing an analysis of automotive fuel economy standards. Results have been presented in testimony before congressional committees. See references in note 12 supra.

[38] See *Changing by Degrees: Steps To Reduce Greenhouse Gases*, supra note 18, pp. 165-166 and cited references.

- the development of an adequate refueling and service support infrastructure, and
- consumer acceptance.[39]

Among policy measures suggested to create a market-pull for alternative fueled vehicles are: 1) giving rebates or tax incentives to purchasers of such vehicles or fuels; 2) requiring private and government fleet operators to purchase or retrofit a minimum number of alternative fueled vehicles; and 3) promoting industry and industry-government joint ventures to accelerate vehicle technology RD&D and commercialization. Development of an adequate refueling and servicing network could be aided by resolving any existing regulatory impediments for commercial distribution of natural gas vehicle fuels, requirements that refiners and large gasoline retailers offer a certain percentage of alternative vehicle fuels, and expanding alternative vehicle fuel subsidies, such as those now offered for ethanol production. Consumer acceptance could be enhanced by government information on the reliability and potential cost savings from alternative fuel vehicles and requiring manufacturers and retrofitters to warrant the performance and reliability of their vehicles and to back it up with effective customer service. At the same time, the Federal Government could support continued RD&D on improving alternative vehicle technologies, including those that would not be commercially ready or cost effective within 5 years, but might be within an additional 5 to 10 years, for example, electric and hydrogen vehicles.

Traffic management and control technologies can reduce vehicle miles traveled and improve the efficiency of traffic movement and save oil. In general, these measures have the advantage of short lead-times and low capital costs. They work best when they have a high degree of local involvement and community support. There has been only limited analysis of the potential oil savings of these technologies, but available studies suggest that while individual measures offer small savings, when grouped together they offer a significant opportunity for both short- and long-term contributions. Congress could fund additional Federal support for the further development and support of traffic management and efficiency improvements through the Departments of Energy and Transportation. Congress could require States and localities to develop or improve local plans and programs for implementation in an emergency or as part of a longer term effort to increase oil displacement capability.

Domestic Oil and Gas Production

Oil replacement technologies can counter the effects of an oil import disruption, but will achieve their maximum replacement potential only if domestic production of oil is maintained at or near current levels and domestic natural gas production increases to meet new demand. Policy options that maintain domestic production and encourage oil and gas exploration and development are thus part of any oil replacement strategy.

The best hopes for maintaining and even slightly increasing domestic oil production in the near term lie in unrecovered oil in already discovered fields rather than in prospects for new large discoveries in frontier areas. Drilling thousands and thousands of wells in existing fields provided fully 70 percent of total U.S. reserves additions from 1979 to 1984.

Legislative options intended to encourage domestic exploration, development and production can be grouped as follows:

1. targeted tax incentives for exploration or production such as tax deductions, credits, depletion allowances;
2. measures that raise the price of oil or natural gas at the wellhead such as import fees or price floors;
3. technical assistance and technology transfer programs;
4. changes in the SPR program to favor certain classes of domestic producers or to include preservation of domestic production potential;
5. opening more Federal onshore and offshore lands to leasing or adopting more favorable lease terms or royalties; and
6. resolving specific regulatory or environmental controversies that are delaying exploration, development, or production.[40]

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[39] For a more extensive discussion see the OTA's recent report, *Replacing Gasoline*, supra note 14.

[40] For an extensive treatment of the pros and cons of policy options to aid the domestic oil industry, see National Petroleum Council, *Factors Affecting U.S. Oil and Gas Outlook*, February 1987.

All of these measures are politically controversial because they often conflict with other public policy goals such as increasing Federal revenues, reducing the deficit, restoring fairness in tax laws, eliminating energy subsidies, protecting the environment, protecting the international competitiveness of U.S. manufacturers, or promoting greater competition among energy sources and suppliers. All approaches raise questions of whether they would actually be effective at spurring incremental production.

Our technical review found that the most attractive opportunities for maintaining domestic production over the near term were continuing development in existing fields, accelerating enhanced oil recovery, bringing shutin or marginal oil wells back into production, and limiting premature well abandonment. All of the policy options listed above could, in some way, affect these prospects. Further study of the relative effectiveness, cost, and incremental oil yields from these options would be needed to determine which would offer the greatest benefits for reducing oil import vulnerability in the near term.

Enhancing Natural Gas Availability

Concerns over natural gas availability include not only the adequacy of domestic production, but also the ability to move gas from the wellhead to the burner tip. Natural gas use in some regions has been constrained because interstate pipeline capacity and storage facilities are insufficient to meet incremental demand. Planned capacity additions, new pipelines, and Canadian gas imports are reported to have faced delays in obtaining needed regulatory approvals. Measures, such as changing FERC procedures for approving new interstate pipelines to expedite regulatory review, while assuring that environmental and competitive issues are satisfactorily resolved, might enhance natural gas availability.

In addition to increasing interstate pipeline capacity, improvements to local distribution systems and gas storage facilities would also be needed to support greater use of natural gas instead of oil. Some local distribution companies, electric utilities, and large industrial users are considering expansion of natural gas storage capacity, including natural gas liquefaction and storage facilities, as a means to overcome seasonal availability problems. Congress may wish to consider requiring the Department of Energy to review technical, environmental, and regulatory issues associated with improving local deliverability and expanding gas storage capacity and to identify any appropriate legislative changes.

In our 1984 report, we found that an aggressive program of natural gas efficiency improvements could result in significant gas savings—sufficient to meet most of the new natural gas demand from deployment of oil replacement technologies. Congress may consider requiring the Department of Energy, in cooperation with State regulatory commissions, to examine the potential for increasing local availability of natural gas through improved conservation and demand side management by gas utilities and to recommend any appropriate legislative changes.

Oil Import Disruption Contingency Planning and Emergency Response

Because technical means alone would be insufficient to offset the loss of oil imports in a major and prolonged supply disruption, the availability of strategic and private stocks and oil emergency contingency plans and authorities assume a greater importance than before. As imports rise, the amount of oil needed for the SPR will also need to increase. Congress recently approved a 1-billion-barrel SPR, but this level will not be reached until the late 1990s. Congress also approved the creation of oil product reserves. Congress may wish to reexamine the adequacy of existing law for responding to prolonged oil import disruptions and to assure that oil emergency plans are kept up to date.

In light of recent experience, Congress may wish to review the structure and operations of the SPR. Among the possible changes that might be considered are clarifying provisions for release of SPR oil to include sharp, panic-driven oil price increases as well as physical shortages, accelerating the SPR fill rate, and providing for automatic adjustment of the SPR fill target to maintain adequate levels of reserves. Other suggestions include adding provisions to accelerate purchases to take advantage of low oil prices or to maintain stripper well production.

OTA's 1984 report noted that the Federal Government was ill-prepared to respond to an oil supply crisis, or even to monitor actual technical capability to deploy oil replacement technologies and the rate of oil replacement. Among options that could be taken in advance of a crisis to redress these shortcomings are collecting and maintaining accurate information on investments in oil replacement technologies and establishing standby oil replacement incentives and taxes. In an oil supply shortfall, the government could rely on the investment monitoring system to determine whether oil replacement was proceeding effectively. If investments were occurring too slowly and market intervention seemed desirable, standby taxes and financial incentives could be activated and increased or modified, as needed, to be sufficiently effective.[41] The advantage of such a strategy is that it allows a flexible and well-defined government response that can be adjusted, depending on the market behavior and response to various levels of incentives. Since our 1984 report, government information collection and reporting have improved only slightly, but are not specifically directed at providing the kinds of timely information and analysis that would be needed in a crisis.

Reducing Oil Import Vulnerability as Part of Long-Term National Energy Policy

Energy security can be viewed not only in terms of a short-term contingency plan, but also from a long-term perspective embracing the three broader and more fundamental national goals of economic health, environmental quality, and national security. As the United States approaches the task of developing a national energy strategy, it makes sense to do so in ways that support these and other related goals. Such a strategy will require a delicate balancing of energy with other objectives. Some energy options advance all three national goals. Others, particularly those that improve efficiency of production and use, may support one goal but run counter to the others. For example, increased reliance on coal and methanol transportation fuels from coal could cut oil import dependence, but exacerbate problems of air pollution and global climate change.

There are no quick and easy technical "fixes" to America's oil import dependence. Major changes in energy systems—and major changes are what would be needed—require decades and unwavering commitment from citizens, political leaders, and industry. Given time, energy is a flexible component of a modern economy, but a long time will be needed to effect a major turnover of the capital stock of energy supply and consumption technology. In the absence of a supply crisis, short-term strategies—either to spur production or to curb consumption—could prove inefficient and traumatic.

The same oil replacement technologies and policies that could prove critical in an oil import crisis also can contribute to achieving a long term goal of reducing import vulnerability. Indeed, many of these technologies offer larger savings over the longer-term than they do as short-term replacement options—improvements in total automobile fleet fuel efficiency and a transition to alternative vehicle fuels both are more effective as long-term rather than short-term options. The additional time for technology development and institutional change under a long-term oil replacement strategy would also enhance the effectiveness and reliability of other technologies. For example, new technologies, such as electric vehicles and fuel cells, could reach commercial viability. In short, a long-term oil replacement strategy offers more robust technology options than does a crisis scenario.

Establishing National Energy Goals

The United States can succeed in easing oil import vulnerability, but only if we establish long-term energy goals and stick to them through periods of both crisis and calm and through high and low oil prices. Certainly, a sensible, comprehensive energy policy must be responsive to sudden changes of events, but it must be fundamentally grounded in long-term strategies.

In many ways, Congress acts as a supreme board of directors for our national enterprise, setting broad policy goals, approving plans to reach these targets, and periodically measuring progress and recharting direction. A similar structured approach could be adopted in establishing a comprehensive national energy strategy. Congress would set broad long-term energy policy goals and approve the implementation program submitted by the President and the Secretary of Energy. (This implementation program would likely include many of the oil replacement options previously discussed under the oil disruption response strategy.) To aid in oversight, Congress could direct the Secretary to develop quantitative indicators of our progress in attaining our targets and report on them periodically. The Secretary might also be required to include in any legislative requests a statement of how new energy programs or appropriations would advance the national energy goals. Congress would review the goals every 5 years and make any necessary modifications or additions.

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[41] See OTA supra note 1, pp. 26-35.

Candidate goals for limiting oil import vulnerability, increasing energy efficiency, and beginning a long-term transition to a post-fossil economy by the year 2010 might include, for example:

1. limiting U.S. net oil imports to not more than 50 percent of annual oil consumption;
2. promoting efforts to diversify sources of world oil production in regions outside the Middle East when such assistance can be aligned with other U.S. policy interests;
3. increasing U.S. energy efficiency (i.e., energy per unit of domestic output) by 20 percent per decade or an average of 2 percent per year;
4. initiating a move towards a post-fossil economy in the long term by reducing carbon intensity by 10 percent in each of the next two decades (equivalent to an average of 1 percent per year average over 10 years);
5. improving the efficiency of the U.S. transportation sector by increasing light-duty fuel efficiency by an average of 2 percent per year; and
6. reducing oil's share of U.S. transportation energy use by 10 percent by 2010.

Having adopted a comprehensive set of national energy goals and an implementation plan for achieving them, other policy initiatives and legislation could then be evaluated based on how they contributed to achieving those goals. For example, an underlying objective for federally supported technology RD&D, and commercialization would be to identify and advance promising technologies to achieve these national energy goals.

CONCLUSION

In facing the prospects of continuing oil import vulnerability and lessened technical capability to respond to severe and prolonged oil disruptions, the United States has three choices:

1. We can continue on the current path and wait until the next disruption occurs before deciding on an appropriate response.
2. We can anticipate that such disruptions will occur and set in place effective measures that enhance our ability to replace oil in response to the disruption.
3. Or, we can begin now to craft a more comprehensive national energy strategy that embraces a long-term goal of reducing our reliance on oil and other fossil fuels and beginning a transition to the eventual post-fossil era, and that does so consistent with other national policy objectives.

Whichever path we choose, success in reducing our oil import vulnerability will require a strong Federal example and the sustained support and cooperation of citizens, business, and government.

Chapter 2

Oil in the U.S. Economy

Contents

Page

INTRODUCTION 29

U.S. OIL CONSUMPTION 29

- Petroleum Product Consumption 29
- Oil Consumption by Sector 31
- Oil Use by Application 34

DOMESTIC PRODUCTION 36

OIL IMPORTS 37

- U.S. Regional Import Oil Dependence 37
- Sources of Imported Oil 37

OIL SUPPLY DISRUPTIONS 38

THE PERSIAN GULF CRISIS, 1990-91 40

OUTLOOK 42

Figures

Figure *Page*

2-1. U.S. Energy Consumption by Energy Source, 1970-89 30

2-2. Petroleum Products Supplied by Type, 1970-89 30

2-3. U.S. Oil Use by Sector, 1970-89 31

2-4. Energy Consumption in the U.S. Transportation Sector, 1989 31

2-5. Energy and Oil Use in the Industrial Sector 32

2-6. Residential Energy Consumption by Fuel and Region, 1987 33

2-7. Commercial Sector Energy Consumption by Fuel and Region, 1986 33

2-8. U.S. Electricity Generation by Fuel Source, 1989 34

2-9. Oil Use by Application and Region, 1989 34

2-10. U.S. Crude Oil Production, 1970-89 36

2-11. Net U.S. Oil Imports, 1970-89 36

2-12. Source of Crude Oil Processed by U.S. Refineries, 1989 37

2-13. Percent of U.S. Imports by Source, 1970-89 38

2-14. Crude Oil Refiner Acquisition Cost, 1979-89 40

2-15. Crude Oil and Unleaded Regular Gasoline Prices, July 1990 to February 1991 41

Tables

Table *Page*

2-1. U.S. Oil Consumption by Application and Region, 1989 35

2-2. World Oil Supply Disruptions, 1951-89 39

Chapter 2

Oil in the U.S. Economy

INTRODUCTION

Eighteen years after the first oil shock of the 1970s, oil continues to fuel much of America's economy. Oil is the major U.S. energy source supplying 42 percent of energy requirements in 1989. (See figure 2-1.) Energy use in the economy as a whole has grown from 74 quadrillion Btus (quads) in 1973 to 81.2 quads in 1989. However, there have been notable shifts in domestic use and production of oil.

Since 1970, domestic crude oil production has declined—falling from 9.6 million barrels per day (MMB/D)in 1970 to 7.6 MMB/D in 1989.[1] Imports have increased to meet domestic needs. In 1989 the United States imported 7.12 MMB/D of crude oil and oil products (about 41 percent of oil supplies), with 1.86 MMB/D coming from Persian Gulf producers. Over the same period, patterns of oil use in the U.S. economy changed as many users converted to other fuels and all sectors became more energy efficient.

This chapter profiles oil consumption and production in the United States and the changes in both over the past two decades. It concludes with a short summary of previous oil supply disruptions and the initial impacts of the Iraqi invasion of Kuwait and subsequent United Nations and allied actions.

U.S. OIL CONSUMPTION

U.S. oil consumption was 17.2 MMB/D in 1989, down from a high of over 18.8 MMB/D in 1978. As a share of total energy use, oil provided about 42 percent of U.S. energy needs in 1989, compared to 49 percent in 1978. From 1979 to 1983, a period of economic downturn and very high oil prices, oil consumption declined 3.6 MMB/D. As oil prices fell and the economy began to expand, oil demand began to grow again and has averaged under 2 percent per year from 1984 to 1989. With the higher oil prices following the Iraqi invasion of Kuwait and the onset of a recession, oil product demand in 1990 was an estimated 2.4 percent lower than in 1989.[2]

There are five primary end-use applications for oil products: space and water heating, process steam and power generation, process heat, transportation, and feedstocks (raw materials used in manufacturing and processing). Oil products used for these applications include motor gasoline, distillate fuel oils, residual fuel oil, liquefied petroleum gases (LPG), jet fuel, and a variety of products grouped under the term "other petroleum products."

Petroleum Product Consumption

Figure 2-2 shows the consumption of petroleum products from 1970 to 1989.

Motor gasoline is a light fuel used almost exclusively to power automobiles and light trucks. At present it has few widely available commercial substitutes. In 1989 motor gasoline constituted about 42 percent of total petroleum product use. Domestic refineries supply most gasoline needs, the rest is imported (about 360,000 barrels per day (B/D) in 1989).

Consumption of motor gasoline hit an annual high of 7.4 MMB/D in 1978 and then declined to 6.54 MMB/D in 1982, owing to higher gasoline prices and substantial improvements in fleet fuel efficiency that more than offset increases in the total fleet and vehicle miles traveled. Lower gasoline prices and economic expansion in the mid-1980s contributed to renewed growth in gasoline demand from 1986 to 1989. Gasoline consumption reached 7.3 MMB/D in 1989.

Distillate fuel oils (Nos. 1, 2, and 4 fuel oils and diesel fuels) are used for diesel transportation fuel, for space heating in homes and in small commercial and industrial facilities, for industrial process heating, and for electricity generation. Distillates accounted for about 18 percent of 1989 oil use. Demand for distillates peaked at 3.4 MMB/D in 1978, dropped to 2.67 MMB/D in 1982, and then rose to 3.15 MMB/D in 1989. The United States imported about 300,000 B/D of distillates in 1989.

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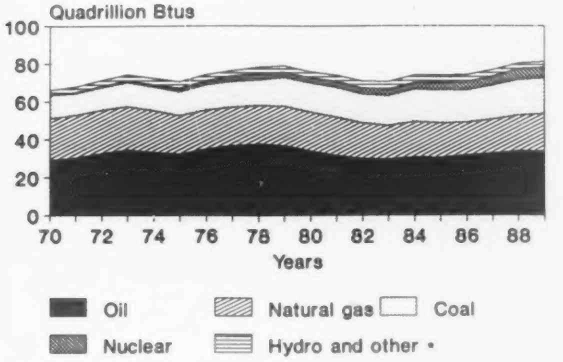
[1] Unless otherwise noted, information on U.S. energy and oil use are drawn from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), hereinafter referred to as *Annual Energy Review 1989*.

[2] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990*, DOE/EIA-0384(90) (Washington, DC: U.S. Government Printing Office, May 1991), table 61.

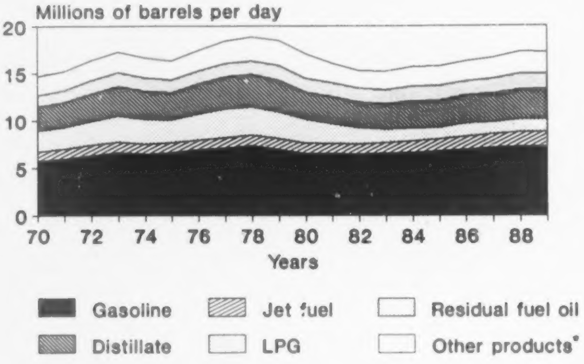
Figure 2-1—U.S. Energy Consumption by Energy Source, 1970-89



*Other includes grid-connected electric power from geothermal, wood, waste, wind, solar, and other sources.

SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 3.

Figure 2-2—Petroleum Products Supplied by Type, 1970-89



* Other products include kerosene, aviation gasoline, petrochemical feedstocks, special naphthas, lubricants, wax, petroleum coke, asphalt, road oil, still gas, pentanes plus, and other miscellaneous products. From 1983 on crude oil burned as fuel is also included in this category.

SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 60.

Residual fuel oil, the heavy oil left after the lighter products have been distilled in the refinery process, is primarily used as a boiler fuel by utilities and industry. A small amount is used as bunker fuel to power ships. Residual fuel oil competes directly with natural gas in industrial and electric generating facilities that can burn either gas or oil, and so its demand is highly tied to the relative price of natural gas. Use of residual fuel oil by utilities and industry has dropped substantially from a peak of 3.07 MMB/D in 1978. About 1.35 MMB/D of residual oil were used in 1989, or just under 8 percent of total oil demand.

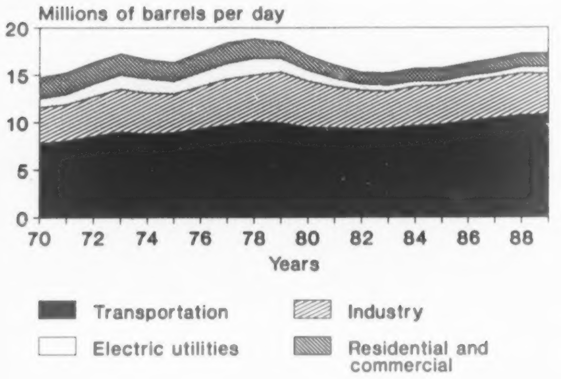
Changes in U.S. refinery capacity in the 1980s reduced the portion of residual fuel oil in refinery yields. Consequently, much of the residual oil consumption has been met by imports. Residual fuel oil imports were as high as 1.85 MMB/D in 1973, but have run at 500,000 to 700,000 B/D through most of the 1980s. Total imports of residual oil were 610,000 B/D in 1989, while exports were 213,000 B/D.

Jet fuel demand was about 1.49 MMB/D in 1989, or about 8.6 percent of total petroleum product use. Demand included commercial, military, and general aviation uses. Following a 3-year drop in demand in 1980-83, jet fuel consumption has risen over 440,000 B/D since 1984. Improved economic conditions, airline fare competition, and travel incentives have boosted passenger miles flown. Imports of jet fuel were 102,000 B/D in 1989.

Liquefied petroleum gases include ethane, propane, butane, and other gases from natural gas processing plants as well as liquefied refinery gases (ethylene, propylene, butylene, and isobutylene) produced from crude oil. Most LPG is derived from crude oil, but some is derived from natural gas. LPG is used as a fuel in the residential and commercial sectors and as a fuel and feedstock in the industrial sector. In 1989 LPG made up 1.66 MMB/D or about 9.6 percent of oil product demand, the highest level of demand in the past 20 years. LPG imports totaled about 180,000 B/D in 1989.

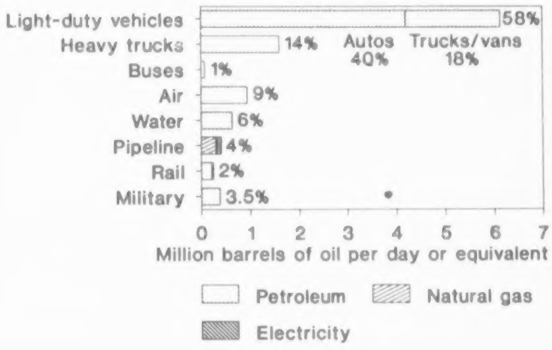
Demand for **other petroleum products** was 2.26 MMB/D in 1989. This category includes petrochemical feedstocks, kerosene, asphalt and road oil, lubricants, waxes, and other oil products. Demand for these products is closely tied to economic conditions in the industrial sector and declined from a high of 2.67 MMB/D in 1979 to a low of 1.86 MMB/D in 1982. This category currently represents about 13 percent of total petroleum product demand. Imports were about 270,000 B/D in 1989.

Figure 2-3—U.S. Oil Use by Sector, 1970-89



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 61.

Figure 2-4—Energy Consumption in the U.S Transportation Sector, 1989



SOURCE: Office of Technology Assessment, 1991, from data in Stacy C. Davis and Patricia S. Hu, *Transportation Energy Data Book: Edition 11*, ORNL-6649 (edition 11 of ORNL-5198) (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991).

Oil Consumption by Sector

Demand for oil in each of the major end-use sectors—transportation, commercial, residential, industrial, and electric utilities—is generally sensitive to price, but the sectors are not equally responsive to changes in price. Patterns of oil consumption and relative shares of demand for the major sectors for 1970 to 1989 are shown in figure 2-3. The largest oil users are the transportation and industrial sectors, which together accounted for 88 percent of total oil demand in 1989. During the late 1980s oil consumption in these sectors grew due to lower oil prices and renewed economic growth, and because there were few commercially available substitutes for petroleum-derived motor vehicle fuels and industrial feedstocks. More detail on oil use in all sectors can be found in chapter 3.

Transportation

The transportation sector encompasses highway, air, rail, water, and pipeline transport and all modes of military transportation.[3] This sector alone accounts for almost 63 percent of the Nation's total oil consumption and about 27 percent of total energy demand. At 10.85 MMB/D in 1989, transportation sector oil demand was the highest it has ever been. Consumption has grown more than 1 MMB/D since oil prices dropped sharply in 1986. Oil supplies over 95 percent of transportation energy needs with natural gas and electricity accounting for the remainder. (See figure 2-4.) The primary petroleum products used are motor gasoline, diesel (distillate) fuel, jet fuel and other aviation fuels, and residual fuel oil for marine transportation.

The major factors influencing transportation demand for motor gasoline and distillate fuels include fleet size (total number of vehicles), fleet mix (kinds of vehicles), fleet fuel efficiency (miles per gallon for all vehicles in the fleet), new vehicle fuel efficiency (miles per gallon for new cars and trucks), total number of vehicle miles traveled, and the rate of replacement of old vehicles by new vehicles.

Economic trends, such as changes in gross national product, personal income, or demographic patterns, also affect petroleum product consumption in the transportation sector.[4] For example, a surge in new

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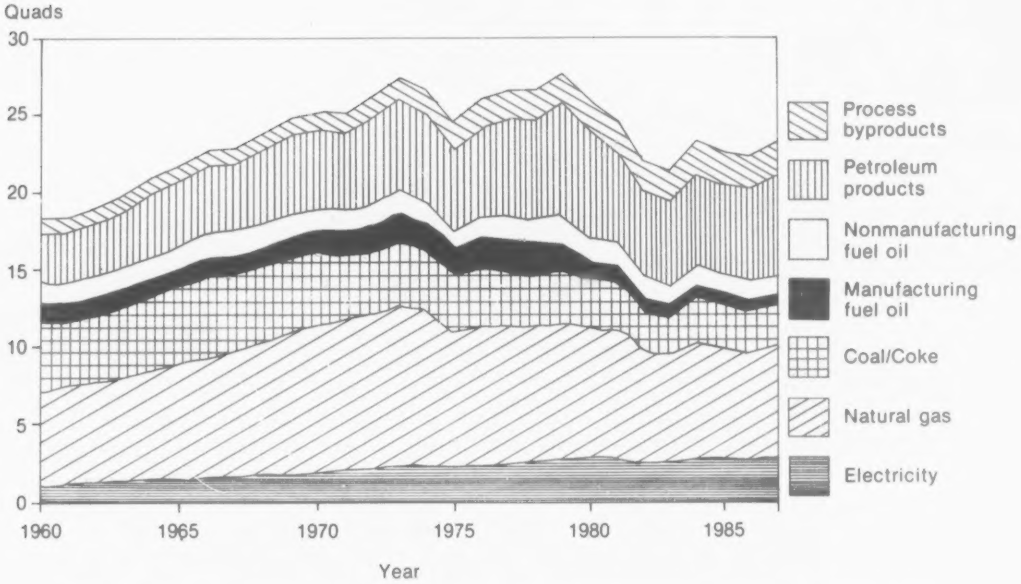
[3] Off-highway transportation for agriculture, construction, and other industrial activities is attributed to the industrial sector.

[4] Demographic influences can push transportation demand in different directions. For example, an increase in the number of drivers tends to increase vehicle miles. As the average age of drivers increases, vehicle miles are expected to decline. However, as the baby boomers move through the family-forming years, a shift in preference to larger cars within that group could somewhat offset overall increases in vehicle efficiencies.

Figure 2-5—Energy and Oil Use in the Industrial Sector



SOURCE: Office of Technology Assessment, 1991, from data in Gas Research Institute, "Industrial Natural Gas Markets: Facts, Falacies and Forecasts," March 1989.

car sales in 1985-86, prompted by an increase in disposable personal income and various dealer incentives, boosted average new vehicle fuel efficiency by twice the anticipated rate. Indeed, shifts in any of the foregoing factors could affect transportation demand by up to several hundred thousand barrels per day, which is a significant portion of any incremental demand met by imports.

Industrial Sector

The industrial sector includes manufacturing, agriculture, forestry, fishing, construction, mining, and oil and gas production. Petroleum supplies about 36 percent of total industrial sector energy needs (excluding energy lost in generation and transmission of electric power sold to the industrial sector). All together, industrial sector activities consume about 25 percent of the total oil demand. Feedstocks comprise about one-half of industrial oil use.

Industrial oil demand has ranged between about 25 and 33 percent of total petroleum product consumption in the past two decades. It reached a high of 5.34 MMB/D in 1979, slid to 3.85 MMB/D in 1983, and grew to 4.26 MMB/D in 1989.

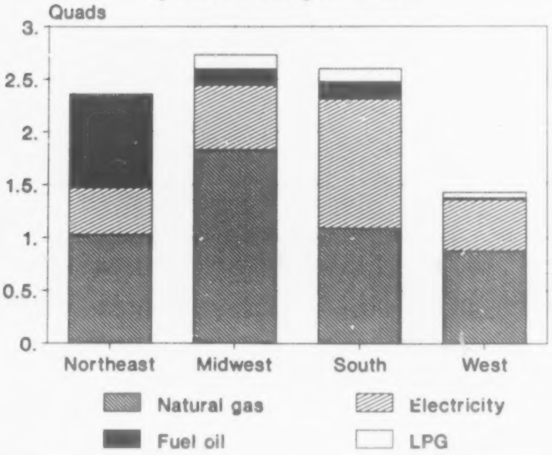
The applications and mix of oil products used in the industrial sector are diverse (figure 2-5). Distillate and residual fuel oils, liquefied petroleum gas, petrochemical feedstocks, and asphalt and road oil make up a large share of industrial oil product demand. Oil products are burned for steam and power generation and process heat, and are used as fuel for industrial and agricultural equipment and as feedstocks for the manufacture of other products.

Industrial oil demand is sensitive to general economic trends. Feedstock demand, the largest category of industrial oil use, generally follows economic growth. Oil use in dual-fuel industrial boilers is tied to the relative prices of oil and natural gas.

Residential and Commercial Sectors

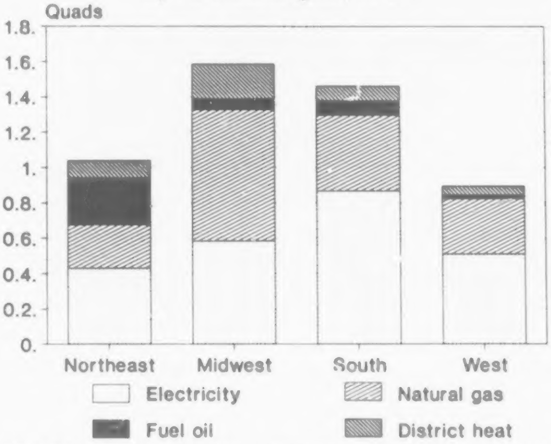
The residential and commercial sectors together consumed about 8 percent of all oil used in the U.S. economy in 1989. From 1973 to 1989, oil demand in

Figure 2-6—Residential Energy Consumption by Fuel and Region, 1987



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987, Part 2: Regional Data*, DOE/EIA-0321(87)/2 (Washington, DC: U.S. Government Printing Office, January 1990).

Figure 2-7—Commercial Sector Energy Consumption by Fuel and Region, 1986



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Nonresidential Buildings Energy Consumption Survey: Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86) (Washington, DC: U.S. Government Printing Office, May 1989), table 11.

the residential and commercial sectors declined from 2.25 to 1.4 MMB/D, mostly because of energy efficiency gains and conversions to other fuels. Oil use actually reached a low of 1.24 MMB/D in 1982 before beginning a gradual increase.

The residential sector consists of single- and multifamily homes, apartments, and mobile homes. About 18 percent of all housing units or 16.4 million residential units use oil as a primary heating fuel.[5] Residential demand is about 5 percent of total demand and consists mostly of space and water heating—mainly in the Northeast. (See figure 2-6.) A map of census regions can be found in the appendix. Residential fuels are primarily distillate fuel oil and LPG. The number of American homes heated by oil products has generally been declining since the 1960s, although the 1980s saw a slight increase in oil heating in areas where electric heat is expensive and natural gas availability limited.

The commercial sector includes offices, stores, and other nonindustrial businesses; educational, health care, and religious institutions; and Federal, State, and local governments. The commercial sector accounts for 3 percent of total oil use. About half of commercial demand is for distillate and the remaining half about equally split between residual fuel oil and LPG. About 18 percent of U.S. commercial buildings, or 750,000 buildings depend on oil products for heat. Commercial oil use is concentrated in the Northeast and in rural and suburban areas of the South and Midwest that have no local natural gas service. (See figure 2-7.)

Growth in oil demand in the residential and commercial sectors primarily reflects increases in the amount of building square footage heated and annual temperature trends. It is tempered by changes in the energy efficiency of new and existing buildings and in their heating equipment. Residential and commercial oil consumption is much less sensitive to price than consumption in other sectors, and shifts in fuel preferences take place slowly. Greater domestic economic activity is expected to increase commercial floor space and thus increase commercial demand. The amount of residential floor space will also grow, but at a slower rate.

Expectations of stable, low oil prices and economic growth in localities not served by natural gas service—such as suburban areas in the Northeast and the Midwest—could favor more use of oil for space

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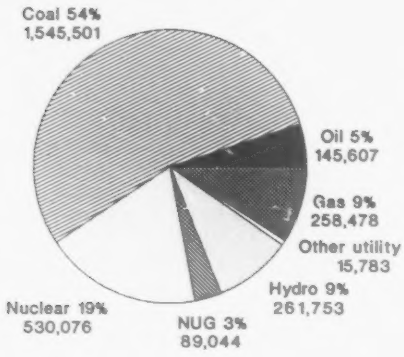
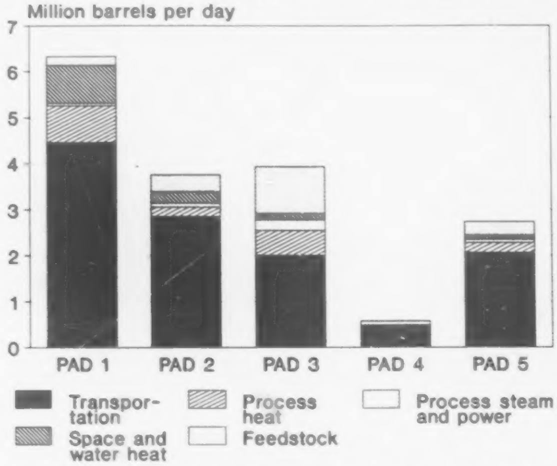
[5] U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987, Part 2, Regional Data*, DOE/EIA-0321(87)/2 (Washington, DC: U.S. Government Printing Office, January 1990), table 2.

Figure 2-8—U.S. Electricity Generation by Fuel Source, 1989



SOURCE: Office of Technology Assessment, 1991, from data in North American Electric Reliability Council, *1990 Electricity Supply and Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990), app. B.

Figure 2-9—Oil Use by Application and Region, 1989



SOURCE: Office of Technology Assessment, 1991, from data in Paul D. Holtberg and David O. Webb, "The Potential for Natural Gas To Displace Oil in Response to the Middle East Crisis and the Implications for the GRI R&D Program," *Gas Research Insights*, Gas Research Institute, November 1990.

heating in preference to other fuels. Continued low oil prices could add to the stock of new residential and commercial buildings heated by oil, delay conversions from oil to competing fuels, and lead to the deferral of major investments in conservation.

Electric Utilities Sector

The electric utility sector includes both public and private utilities that generate and or sell electricity, primarily to the public.[6] Electric utilities burned 740,000 B/D of oil products in 1989, about 4.3 percent of total oil consumption. Oil-fired generation is concentrated in the Northeast, California, Florida, and Hawaii.[7] Almost 90 percent of oil used by electric utilities is residual fuel oil. Electric utilities account for about 36 percent of U.S. energy demand, but only about 5.7 percent of utility energy needs are met by petroleum products. (See figure 2-8.)

Demand for oil for power generation has been declining since the 1970s and is now less than half what it was at its peak of 1.75 MMB/D in 1978. The reduction in oil use can be attributed to fuel switching (mostly to natural gas) in dual-fuel capable facilities and the replacement or substitution of older oil-fired capacity with new coal, nuclear, and natural gas units. Demand for oil for power generation is tied to the relative prices of oil and competing fuels, generating capacity needs and availability, weather conditions, and the seasonal availability of natural gas. At present oil and natural gas prices, oil-fired units are primarily used as peaking capacity or when other (less expensive) capacity is unavailable. A sharp drop in oil prices, steep growth in peak electricity demand, or a tightening of natural gas supplies could spur an increase in utility oil use.

Oil Use by Application

Figure 2-9 shows how oil was used for transportation, feedstocks, process steam and power generation, space and water heating, and process heat. It also shows the relative shares of these end-use applications in 1989.[8] There are regional variations in oil use, but transportation is the dominant category in all regions.

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[6] Fuel consumption in industrial and commercial self-generation and cogeneration is usually attributed to those sectors, although some of these generators sell power to electric utilities.

[7] Hawaii and many remote communities in Alaska are almost exclusively dependent on oil for power generation; but the amounts used are small compared to other States.

[8] Information on end-use applications and consumption are from Paul D. Holtberg and David O. Webb, "The Potential for Natural Gas to Displace Oil in Response to the Middle East Crisis and Implications for the GRI R&D Program," *Gas Research Insights*, Gas Research Institute, November 1990.

Table 2-1—U.S. Oil Consumption by Application and Region, 1989
(thousand barrels per day)

Application	PAD 1	PAD 2	PAD 3	PAD 4	PAD 5	Total
Space & water heating	826	254	140	29	96	1,345
Transport	4,462	2,856	2,014	401	2,063	11,796
Process steam & power generation	797	197	528	42	208	1,772
Process heat	47	84	234	19	67	450
Feedstock	204	366	1,019	84	290	1,962
Total	6,335	3,757	3,935	575	2,724	17,325

SOURCE: Office of Technology Assessment, 1991, from data in Paul D. Holtberg and David O. Webb, "The Potential for Natural Gas To Displace Oil in Response to the Middle East Crisis and the Implications for the GRI R&D Program," *Gas Research Insights*, Gas Research Institute, November 1990.

Combining all sectors, almost 70 percent of the oil used in the United States in 1989—11.8 MMB/D—was used to move people and things. Gasoline and diesel fuel for cars, trucks, buses, and motorcycles made up over two thirds of total transportation demand. Off-highway uses, including commercial and military aircraft, ships, trains, mining and construction equipment, and farm vehicles, used about 3 MMB/D.[9] About half of off-highway demand was for jet fuel.

Regional oil consumption for transportation usually reflects population. Transportation's share of total oil demand varies among regions from 51 percent in the gulf coast Petroleum Administration for Defense District (PAD 3) to 76 percent in the west coast (PAD 5). A map of PAD districts can be found in the appendix.

More than 1.96 MMB/D of petroleum feedstocks were supplied in 1989, about 11 percent of total oil demand. Since this demand is substantially all for oil refineries and petrochemical plants, more than half of feedstock uses were in PAD 3. Significant amounts of feedstocks were also used in the west coast, PAD 5.

Oil products used for process steam and power generation totaled almost 1.8 MMB/D in 1989, or about 10 percent of total oil use. Consumption is split almost equally between the industrial and electric utility sectors. Strong regional use patterns are evident, with over 85 percent of utility demand in the east coast, PAD 1, and over half of industrial demand in the gulf coast, PAD 3. Industrial consumption is concentrated in the petrochemical and refining industries; however, a significant share of this demand is met by waste products, such as still gas.

Space and water heating consumed 1.3 million barrels of oil in 1989 or just under 8 percent of the total. About 90 percent of consumption was distillate fuel oil for space heating. LPG, kerosene, and residual fuel oil account for the remaining products used. Space heating use is highest on the east coast,[10] PAD 1, and in the Midwest, PAD 2, as shown in table 2-1. Together these regions account for 80 percent of space and water heating use.

About 450,000 B/D of oil products were burned to provide process heat. This represents slightly just under 3 percent of total oil demand in 1989. Petrochemical plants and refineries account for much of

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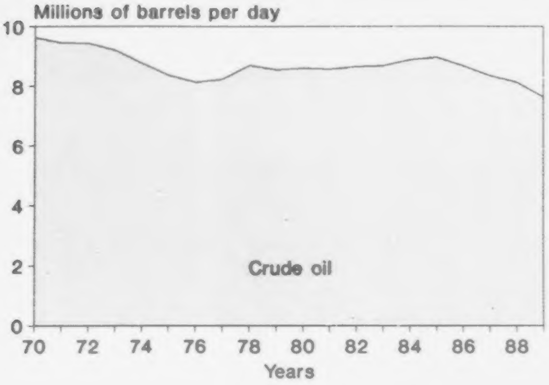
[9] Off-highway oil consumption by farm vehicles and mining and construction equipment is generally attributed to the industrial sector rather than the transportation sector in tallying sectoral energy use.

[10] Half the consumption in PAD 1 is in just four States: New York, New Jersey, Massachusetts, and Pennsylvania.

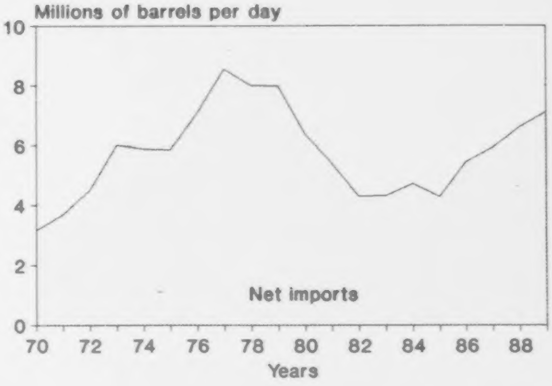
Figure 2-10—U.S. Crude Oil Production, 1970-89



*Includes lease condensate

SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 50.

Figure 2-11—Net U.S. Oil Imports, 1970-89



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 50.

this consumption, and waste oils meet a significant portion of this demand. About half of process heat applications are located in the gulf coast, PAD 3.

DOMESTIC PRODUCTION

U.S. crude oil production reached an all time high of 9.6 MMB/D in 1970. This was followed by 6 years of declining output until higher prices and new Alaskan North Slope production reversed this trend. Oil production climbed back to 8.97 MMB/D by 1985 (see figure 2-10). In 1986, in the wake of a steep drop in world oil prices, U.S. production began to decrease again. By 1989, domestic crude oil production was 7.63 MMB/D—1.34 million barrels less than in 1985. The production of natural gas plant liquids, which hit a high of 1.74 MMB/D in 1973-74, was at 1.55 MMB/D in 1989, its lowest level in 20 years.

Oil exploration activities are a primary key to maintaining reserve additions to sustain production. Exploration activities surged in the late 1970s because of high oil prices and the expectation that even higher world oil prices would prevail. In 1981, as a result of this rapid industry expansion, the main indicators of exploratory activity reached record peaks—3,970 rotary rigs operating (monthly average), 681 seismic crews active (weekly average), and a total of over 17,500 exploratory wells completed.[11] When world oil prices began to slide, domestic exploration activities fell too. The free fall in world oil prices in 1986 further devastated domestic exploration and development. The number of wells drilled plunged to 201, and rotary rigs active totaled only 964—less than half the number operating a year before.[12] Exploratory wells completed dropped to 7,150. As oil prices began to firm up, albeit at much lower real levels in the late 1980s, there was a modest upswing in domestic exploration and development investment. However, key indicators still hit a 40-year low in 1989—869 rotary rigs in operation, 132 seismic crews active, and about 5,220 exploratory wells completed.[13] The drop in activity brought about a shrinking in the infrastructure of the domestic oil industry—a reduction in the availability of equipment, skilled workers, and supporting manufacturing and maintenance services capability that could slow any future expansion of domestic exploration.

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[11] *Annual Energy Review 1989*, supra note 1, p. 89, tables 41 and 42.

[12] For further discussion of the impacts on the domestic petroleum industry, see U.S. Congress, Office of Technology Assessment, *U.S. Oil Production: The Effect of Low Oil Prices— Special Report*, OTA-E-348 (Washington, DC: U.S. Government Printing Office, September 1987).

[13] The higher oil prices in 1990 brought about a brief upswing in exploration indicators. According to preliminary information released by the American Petroleum Institute, domestic oil production in the first half of 1991 was up by 0.6 percent over 1990, reversing the recent pattern of declining output. API attributed the production rise to increased exploration and production activity in 1990, better economic conditions for producers, and technology improvements. See "Oil Demand Falls to Lowest Level Since 1983," *The Energy Daily*, July 18, 1991, p. 4.

OIL IMPORTS

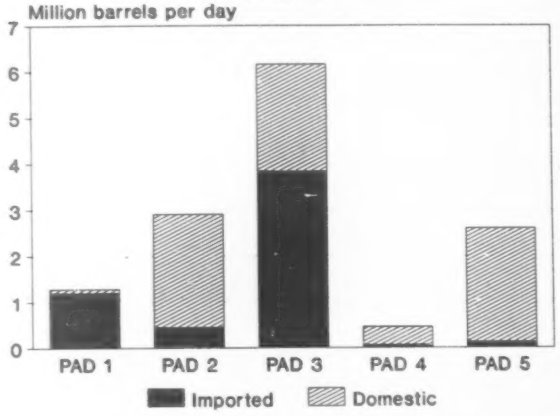
Imports fill the gap between domestic production and demand. In 1970, net oil imports totaled 3.16 MMB/D and climbed to reach 8.56 MMB/D (46 percent of U.S. oil consumption) in 1977 (see figure 2-11). As oil demand dropped in response to very high oil prices, net import levels declined to 4.29 MMB/D in 1985 (27 percent of oil use). Lower world oil prices and rising demand drove net imports of crude oil and petroleum products to 7.12 MMB/D in 1989 (41 percent of domestic consumption). Gross oil imports in 1989 were 7.98 MMB/D and exceeded domestic crude production for the first time since 1977. Imports of crude oil predominate, but imports of petroleum products have been increasing too.

The United States imported a total of 1.86 MMB/D of crude oil, natural gas liquids, and refined products from the Persian Gulf nations in 1989—more than 1.5 MMB/D more than in 1983.[14] Persian Gulf imports made up about 11 percent of total U.S. consumption and and 23 percent of gross imports for 1989. For the first half of 1990, Persian Gulf imports were running slightly ahead of those of the previous year. In the first quarter of 1990, U.S. imports of crude oil and refined products totaled 8.4 MMB/D. Of this, 2.3 MMB/D came from Persian Gulf countries representing about 27 percent of our imports and about 15 percent of Persian Gulf production.[15] By the end of 1990, annual net imports were about 7.1 MMB/D, Persian Gulf imports were about 2 MMB/D.

U.S. Regional Import Dependence

Under current oil supply and distribution patterns, there are clear regional dependencies on imported crude and refined products. Any interruption in oil imports would likely be felt first and most severely in those regions that are most dependent.

Figure 2-12—Source of Crude Oil Processed by U.S. Refineries, 1989
(by region)



SOURCE: Office of Technology Assessment, 1991, from data in Paul D. Holtberg and David O. Webb, "The Potential for Natural Gas To Displace Oil in Response to the Middle East Crisis and the Implications for the GRI R&D Program," *Gas Research Insights*, Gas Research Institute, November 1990.

In 1989, the United States imported 5.8 MMB/D of crude oil. Most crude oil imports enter the country through east coast (PAD 1) and gulf coast (PAD 3) ports. Figure 2-12 shows the origins of refinery throughput by region. Imports provide over 95 percent of refinery throughput in the east coast and about 60 percent for gulf coast refineries. The west coast (PAD 5) and Rocky Mountain (PAD 4) regions are largely self-sufficient, producing and refining their own oil. Domestic crude supplies the largest share of refinery throughput in the Midwest (PAD 2); most of this crude comes from PAD 3, however.

Imports of petroleum products totaled 2.2 MMB/D in 1989. This was considerably less than the 3 MMB/D imported in 1973; however, much of the difference reflects a sharp drop in residual oil. U.S. refiners exported 717,000 B/D of petroleum products in 1989, the highest level ever. Netting out these exports, the United States used about 1.5 MMB/D of imported products. Over 95 percent of imported petroleum products are used in the east coast (PAD 1).

Sources of Imported Oil

Over the past 20 years, the United States has diversified its sources of imported oil, as shown in figure 2-13. The major U.S. oil suppliers include Saudi

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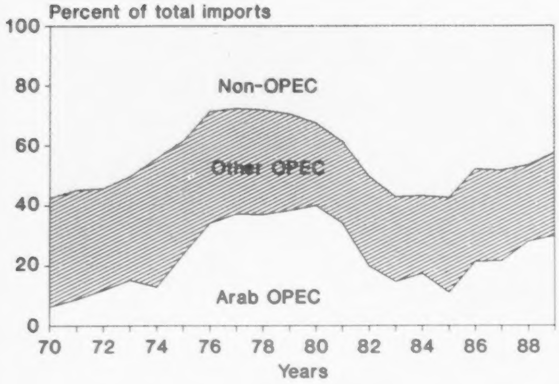
[14] U.S. Department of Energy, Energy Information Administration, *International Petroleum Statistics Report*, DOE/EIA-0520(91/02), February 1991, table 3.6.

[15] Gas Research Institute, supra note 8.

Figure 2-13—Percent of U.S. Oil Imports by Source, 1970-89



SOURCE: Office of Technology Assessment ,1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 56.

Arabia, Venezuela, Canada, Nigeria, and Mexico. In 1989, imports from the Organization of Petroleum Exporting Countries (OPEC) made up 57.6 percent of total net imports, the highest level since 1981, but less than in 1976 through 1980 when OPEC's share was more than 70 percent.[16] Imports from OPEC countries have increased since 1985, much of the additional oil coming from Saudi Arabia. In 1981 Arab OPEC countries accounted for 54 percent of U.S. net imports. This share dropped to 11 percent in 1985, but increased to 29 percent in 1989.[17]

OIL SUPPLY DISRUPTIONS

Before the August 1990 Iraqi invasion of Kuwait and the subsequent United Nations sanctions, the world had weathered a number of oil supply disruptions. In the past 20 years there have been three serious oil supply disruptions resulting in the loss of significant shares of crude oil production for periods of several months. These included the Arab oil embargo (1973), the Iranian revolution (1978-79), and the outbreak of the Iran-Iraq war (1980). Many industry analysts would also add the 1986 plunge in world oil prices to the list of oil crises, because of its devastating impact on the economic viability of the oil industry in high-cost regions, including the United States. In addition to these major disruptions there were smaller disruptions caused by wars, political unrest, and accidents. As shown in table 2-2, about half of these disruptions lasted 5 months or more. The two major oil crises of the 1970s, however, lasted under 6 months. The largest disruption was the production loss of 3.7 MMB/D following the Iranian revolution in 1978. These shortfalls were met to varying degrees by conservation induced by higher prices, the drawdown of commercial inventories, and increased production from excess capacity.

An analysis of these disruptions by the Interagency Working Group review of Strategic Petroleum Reserve (SPR) size options concluded:[18]

- Thirteen disruptions resulted in the loss of 1 percent or more of consumption. A similar disruption today would amount to about 500,000 B/D (using the "free world" oil market). The group found this to be "mathematically equivalent to a 30 percent chance of a disruption of at least this size in any given year."
- Five disruptions involved the loss of 5 percent or more of consumption—roughly equivalent to 2.5 MMB/D of oil at present. This equates to a 13-percent chance of this size disruption in a given year.
- Overall, there is a 10-percent likelihood (plus or minus 5 percent) of a modest supply disruption of 8 to 11 MMB/D occurring between 1995 and 2010. This estimate is subject to considerable uncertainty after 2000 because of the large number of unknown factors involved—e.g., global oil prices, oil demand, new technologies, new oil discoveries, political and military developments—making the assessment perhaps better characterized as "informed speculation."
- The United States is better equipped now to deal with an oil supply disruption than in 1979 because of the larger unused world oil production capacity at present (an estimated 5 to 7 MMB/D in 1990) and the strategic petroleum stock pro-

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[16] Current OPEC members are Algeria, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

[17] Arab OPEC countries consist of Algeria, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, and the United Arab Emirates.

[18] Interagency Working Group, *Strategic Petroleum Reserve: Analysis of Size Options*, DOE/IE-0016 (unclassified report), February 1990, p. IV-2.

Table 2-2—World Oil Supply Disruptions, 1951-89

Dates	Event	Size of supply shortfall (MMB/D)	Duration (months)	World oil consumption (MMB/D)	Percent of world consumption	Percent change in world oil prices
March 1951–October 1954	Iranian fields nationalized	0.7	44	13.2	5.30	+12.9
November 1956–March 1957	Suez War	2.0	4	17.5	11.43	–1.6
December 1966–March 1967	Syrian transit fee dispute	0.7	3	34.3	2.04	NC
June 1967–August 1967	Six Day War	2.0	2	40.0	5.00	NC
July 1967–October 1968	Nigerian Civil War	0.5	15	40.1	1.25	–37
May 1970–January 1971	Libyan price controversy	1.3	9	48.0	2.71	+25
April 1971–August 1971	Algerian-French nationalization struggle	0.6	5	50.2	1.20	NC
March 1973–May 1973	Lebanese political conflict	0.5	2	58.2	0.86	+26
October 1973–March 1974	October Arab-Israeli War	1.6	5	58.2	2.75	+276
April 1976–May 1976	Civil War in Lebanon	0.3	2	60.2	0.50	NC
May 1977	Damage at Saudi oilfield	0.7	1	62.1	1.13	NC
November 1978–April 1979	Iranian Revolution	3.7	6	65.1	5.68	+82.4
October 1980–January 1981	Outbreak of Iran-Iraq War	3.0	3	60.4	4.97	+9.8
July 1988–November 1989	U.K. Piper Alpha offshore platform explosion	0.3	2	49.8	0.60	+23.4
December 1988–March 1989	U.K. Fulmer floating storage vessel accident	0.2	4	51.6	0.39	+7.9
April 1989–June 1989	U.K. Cormorant offshore platform	0.5	2	51.6	0.97	–17.48

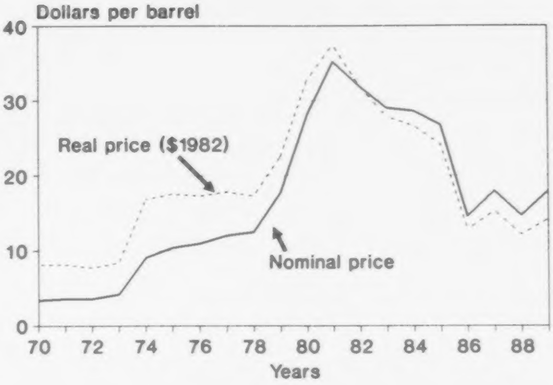
NC = no change

SOURCE: Office of Technology Assessment, 1991, from information in Interagency Working Group, *Strategic Petroleum Reserve: Analysis of Size Options*, DOE/IE-0016 (unclassified report), February 1990, tables IV-1 and IV-2.

gram of International Energy Agency (IEA) member countries (with holdings of over 1 billion barrels at the end of 1989).

The economic impacts of disruptions often outlasted the duration of the actual supply losses. The effects on oil prices and on the economies of oil-consuming nations were, in the opinion of some, out of proportion to the actual shortfall.[19] The impacts were amplified by the interaction of government policies, and consumer and supplier fears as played out in spot markets. Figure 2-14 shows oil price trends in nominal and 1982 dollars from 1970 to 1989. As noted in the 1984 OTA assessment, the sharp price increases persisting after the oil shocks of the 1970's were, in themselves, effectively a type of oil supply curtailment.

Figure 2-14–Crude Oil Refiner Acquisition Cost, 1979-89
(composite nominal and real prices, 1982 dollars)



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 68.

THE PERSIAN GULF CRISIS 1990-91[20]

On August 2, 1990 Iraqi troops occupied Kuwait. The invasion came some two weeks after Iraqi President Saddam Hussein had accused Kuwait of overproducing its OPEC quota and pushing world oil prices down.

The initial charges, which surfaced publicly on July 17, were followed by claims that Kuwait was draining Iraqi oil at wells situated near the border and by veiled threats that it would take action if matters were not resolved. Shortly thereafter, Iraq began moving troops to its border with Kuwait. Other Arab States began what proved to be unsuccessful efforts to mediate the dispute.

These actions were promptly reflected in world oil markets. On July 17, 1990, West Texas Intermediate (WTI) crude oil futures closed at $17.69/barrel (bbl), up slightly from the previous week in anticipation of an expected OPEC agreement to raise oil prices.[21] At the July 27th OPEC ministers meeting, agreement was reached on a production ceiling of 22.5 MMB/D and a target price of $21/bbl. By July 30th WTI, the benchmark U.S. crude oil, closed at $21.59/bbl on the futures exchange.

Immediately following the invasion, President Bush froze Iraqi and Kuwaiti assets in the United States, and banned trade and other transactions with Iraq. The House and Senate also responded with legislation to support the executive order. The United Nations Security Council passed Resolution 660 calling for Iraqi withdrawal from Kuwait. The European Community and Japan joined the boycott on oil imports from Iraq and Kuwait. On August 6, the U.N. Security Council passed Resolution 661 prohibiting U.N. member nations from importing any Iraqi or Kuwaiti products or tranferring funds to either nation.

Oil prices rose to $23.71/bbl on news of the invasion and at the end of one week, crude oil prices rose to $28.05/bbl on world markets. The crude price rise quickly translated into higher gasoline prices at the pump. (See figure 2-15.)

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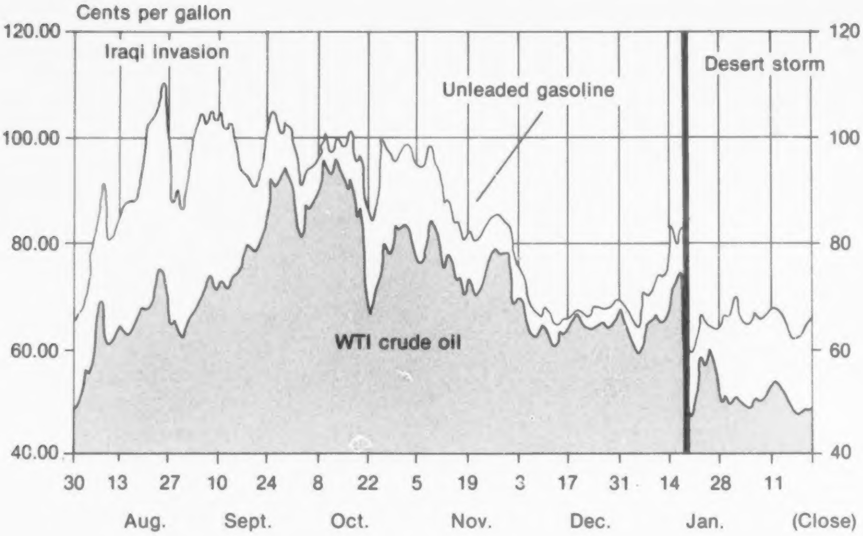
[19] See, for example, the extensive discussion of the impacts of the oil disruptions in the 1970s and 1980s in National Petroleum Council, *Factors Affecting U.S. Oil and Gas Outlook*, February 1987.

[20] Details on actions following Iraqi invasion of Kuwait are from Clyde R. Mark and Renee Stasio, "Iraq-Kuwait Crisis: A Chronology of Events, July 17, 1990-February 7, 1991," Congressional Research Service, Feb. 8, 1991, and from U.S. Department of Energy, Energy Information Administration, *Daily Energy Situation Analysis Reports*, August 1990-March 1991.

[21] "OGJ Newsletter," *Oil and Gas Journal*, vol. 88, July 23, 1990.

Figure 2-15—Crude Oil and Unleaded Regular Gasoline Prices, July 1990 to February 1991



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, "Daily Energy Situation Analysis Report," various issues August 1990 - March 1991.

Within a week of the invasion, the United States and other nations began to mobilize forces to aid in the defense of Saudi Arabia. On August 12, the President committed U.S. naval forces to halt all Iraqi imports and exports. Iraq announced its annexation of Kuwait and interned thousands of U.S. and other nationals in Iraq and Kuwait. On August 25, the U.N. Security Council authorized navies deployed in the Middle East to use force to enforce the embargo against Iraq. By August 22, crude oil prices closed at $31.22/bbl, the highest level in 5 years. On August 29, OPEC members agreed to increase production quotas to make up for the loss of Iraqi and Kuwaiti crude.

Throughout the fall, while official and unofficial diplomatic efforts continued to try to pursuade Iraq to release the hostages and withdraw from Kuwait, ground, air and sea forces from many nations massed in the Persian Gulf. U.S. forces would eventually exceed 500,000 troops. Oil prices were up and stayed up, reaching $40/bbl on October 11 and then retreating to close at $33.82/bbl for WTI on October 19.

On November 29, 1990, the Security Council passed Resolution 678 authorizing member states to "use all necessary means" to remove Iraq from Kuwait and assure compliance with other U.N. resolutions. President Bush invited Iraq to meet to discuss the Persian Gulf Crisis between December 15 and January 15, 1991. WTI closed at $29.08/bbl on November 30th. Crude oil spot and futures prices trended slightly lower as preliminary talks got nowhere, Iraqi forces dug in, and coalition troops, equipment, and material built up.

On January 8, 1991, the President asked for a congressional resolution approving the use of all necessary means including force to end Iraqi occupation of Kuwait. WTI was $27.50/bbl. On January 12, following 2 days of prolonged debate, the House and Senate sent a resolution (H.J. Res. 77, P. 102-1) to the President authorizing the use of military force to implement U.N. Resolution 678 and expel Iraq from Kuwait. On January 16, as called for in the joint resolution, the President certified his decision to use military force after all diplomatic efforts to enforce Iraqi compliance had failed. Allied aircraft then began bombing Iraqi installations in Iraq and Kuwait in the beginning of an intense military campaign dubbed "Desert Storm." WTI crude prices rose to close at $32.25/bbl, only to fall to $21.48/bbl on January 17.

In the weeks that followed, the aerial bombardment continued unabated and oil prices hovered around $21/bbl.

In early February, Iraqi representatives began signaling a willingness to withdraw from Kuwait, but rejected compliance with all U.N. resolutions. Efforts to negotiate a diplomatic resolution again failed. On February 22, WTI spot prices closed at $17.43/bbl. On February 23, coalition forces began a ground invasion to liberate Kuwait, and in less than 100 hours forces led by Kuwaiti, Saudi, and other arab forces entered Kuwait City. Military operations were suspended on February 28, pending agreement on a permanent ceasefire among the parties. The oil fields of newly liberated Kuwait were left blazing by retreating Iraqi troops. Preliminary estimates were that it could take 1 to 2 years just to put out the fires.

Even as coalition forces stopped their assault against Iraq, ethnic and religious minorities within Iraq mounted armed resistance against the government of Saddam Hussein. This rebellion was met with ruthless retaliation by the remaining loyal armed forces. The counterattack created a flood of refugees. Even as U.S troops were being sent home from the Persian Gulf, other troops were deployed to Northern Iraq to create safe havens for Kurdish refugees. The situation in the region remains unstable. Oil prices, however, have remained low. By early July, average world crude oil prices were $16.72/bbl.[22]

The embargo of Iraqi and Kuwaiti crude and product exports removed 4.9 MMB/D from world markets, about 9 percent of free world production. This supply disruption came at a time when world oil stocks were higher than in recent years and oil production capacity worldwide exceeded demand by more than 5 MMB/D. As in previous disruptions, the price impacts were far larger than any physical shortage of crude or oil products. Even so, oil prices have not reached the levels set in 1981 of $40/bbl—which adjusted for inflation would equal a price of $55/bbl today. In fact, except for a brief tightening of petroleum feedstocks in Asian markets owing to the loss of Kuwaiti refining capacity, oil supplies remained plentiful. By the beginning of November surge production capacity had wiped out any crude shortfall, and by early January there was again surplus production capacity available—excluding any Iraqi or Kuwaiti capacity.

OUTLOOK

It is too soon to know the full outcome of events surrounding the 1990 Iraqi invasion of Kuwait and the Persian Gulf war. The enhanced influence of futures markets on the volatility of oil prices was amply demonstrated. Yet, there were few, if any, actual shortages of crude oil or refined products. The combination of conservation, underutilitzed production capacity, private oil stocks, and government-held strategic reserves has so far been great enough to meet the world's oil needs. Yet the costs of the disruption went far beyond any loss of production. Higher oil prices added tens of billions of dollars to world and U.S. oil bills. Great hardships were imposed on many poor and populous developing countries, which are even more reliant on imported oil than the United States. The full costs of mounting the Desert Shield-Desert Storm operations have yet to be quantified, but are likely to total well into the tens of billions of dollars.

Although allied forces succeeded in ousting Iraqi invaders from Kuwait and restoring some sense of security to other nations in the Gulf, the destruction wrought on Kuwaiti and Iraqi oil fields will not be so quickly repaired.

What will happen with another oil supply crisis? How well is this Nation equipped to meet this challenge? Will our technological options prove as sure and swift as our the military response to Saddam Hussein's aggression? The following chapter examines our technical capability to replace lost oil imports in the event of a serious and prolonged oil supply disruption.

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[22] U.S. Department of Energy, Energy Information Admininstration, *Weekly Petroleum Status Report: Data for Week Ending July 12, 1991*, DOE/EIA-0208(91-30) (Washington, DC: U.S. Government Printing Office, July 17, 1991), table 12.

Chapter 3

U.S. Technical Potential for Replacing Imported Oil

Contents

Page
INTRODUCTION 47
Background 47
Revised Oil Disruption Scenario and Technology Selection Criteria 48
RESIDENTIAL AND COMMERCIAL SECTORS 50
Oil Use in the Residential and Commercial Sectors 50
Oil Replacement Options 52
Deployment Considerations 58
ELECTRIC UTILITY SECTOR 60
Oil Replacement Options 62
Deployment Constraints and Schedule 67
THE INDUSTRIAL SECTOR 69
Patterns of Industrial Oil Use 69
Oil Replacement Potential 72
Deployment Considerations and Costs 79
TRANSPORTATION SECTOR 81
Oil Use in the Transportation Sector 81
Oil Replacement Options for Light-Duty Vehicles 81
Limited Oil Replacement Potential in Other Transport Sectors 89
Deployment Considerations and Schedule 91
DOMESTIC PETROLEUM SUPPLY 92
Potential Oil Production 92
Constraints to Production 94
Estimated 1995 Domestic Petroleum Supply 96
Investment Cost 96
OTHER FACTORS AFFECTING OIL REPLACEMENT POTENTIAL 96
Uncertainties in Achieving Technical Replacement Potential 97

Figures

Figure *Page*
3-1. Residential Space Heating by Region and Main Heating Source, 1987 52
3-2. Commercial Buildings Space Heating by Fuel and Region, 1986 53
3-3. Generation of Electricity by Electric Utilities by Region and Energy Source, 1989 61
3-4. Electric Utility Generating Capacity by Region and Energy Source, 1989 61
3-5. Planned New Non-Oil Capacity Additions in 1990 to 1995 in Oil Dependent NERC Regions 63
3-6. Oil Use in the Industrial Sector by Region and Application 71
3-7. Profile of Energy Use in the Industrial Sector, 1985 71
3-8. Distribution of Industrial Boilers by Region and Primary Fuel Type 74
3-9. Chemical Feedstocks: Sources and Applications 78
3-10. U.S. Petroleum Supply, 1970-89 92
3-11. U.S. Technical Capability To Replace Lost Imports in an Oil Supply Disruption, 5-Year Deployment Schedule by Sector 97
3-12. U.S. Technical Capability To Replace Lost Imports in an Oil Supply Disruption, Replacement Potential by Source 97

Tables

Table *Page*

3-1. U.S. Oil Use by Sector, 1983 and 1989 48
3-2. U.S. Oil Replacement Technical Potential, 1984 and 1991 48
3-3. Oil Replacement Options Selected for Assessment 50
3-4. Oil Replacement Options Excluded From Assessment 51
3-5. Consumption of Petroleum Products in the Residential and Commercial Sectors, 1989 52
3-6. Estimated Oil Replacement Potential in the Residential and Commercial Sectors 52
3-7. Energy Use in the Residential Sector by Region, 1987 53
3-8. Characteristics of Households Heated by Oil and LPG 54
3-9. Characteristics of Commercial Buildings Heated by Oil or Propane From 1986 Nonresidential Buildings Energy Consumption Survey 55
3-10. Deployment Schedule for Oil Replacement Technologies in the Residential and Commercial Sectors 59
3-11. Estimated Investment Costs for Oil Replacement Technologies in the Residential and Commercial Sectors 60
3-12. 1989 Oil and Gas-Based Electric Generation and Fuel Consumption by Region 61
3-13. Estimated Oil Replacement Potential in the Electric Utility Sector 62
3-14. Deployment Schedule for Oil Replacement Technologies in the Electric Utility Sector 69
3-15. Estimated Investment Costs for Oil Replacement Technologies in the Electric Utility Sector 70
3-16. Industrial Consumption of Oil Products, 1979, 1983, and 1989 72
3-17. Industrial Oil Use: Consumption in the Manufacturing and Nonmanufacturing Subsectors, 1989 73
3-18. Estimated Oil Replacement Potential in the Industrial Sector 73
3-19. Deployment Schedule for Oil Replacement Technologies in the Industrial Sector 80
3-20. Estimated Costs for Oil Replacement Technologies in the Industrial Sector 80
3-21. Oil Consumption in the Transportation Sector, 1989 82
3-22. Fuel Economy Data for Light-Duty Vehicles, 1984-90 83
3-23. Alternate Scenarios for Efficiency Gain in the Light-Duty Fleet, 1991-95 84
3-24. Low Efficiency Gain Scenario, 1991-95 Efficiency Improvement for the Light-Duty Vehicle Fleet 85
3-25. High-Efficiency Gain Scenario, 1991-95 Efficiency Improvement for the Light-Duty Vehicle Fleet 86
3-26. Estimated Oil Replacement Potential in the Transportation Sector 90
3-27. Deployment Schedule for Oil Replacement Technologies in the Transportation Sector 91
3-28. Estimated Investment Costs for Oil Replacement Technologies in the Transportation Sector 91
3-29. Estimated 1995 Domestic Petroleum Supply 96
3-30. Summary of Estimated Oil Replacement Potential 98
3-31. Summary of Estimated Investment Costs for Oil Replacement Technologies 99
3-32. Summer Electricity Supply Data for Oil-Dependent NERC Regions (MW) 100

U.S. Technical Potential for Replacing Imported Oil

INTRODUCTION

This chapter looks at U.S. technical potential to replace imported oil in the residential, commercial, electric utility, industrial, and transportation sectors. Technical replacement potential refers to the capability to replace oil with other energy sources or to reduce oil use through efficiency improvements while providing an equivalent level of energy services (e.g., light, heat, power, transport). It is distinct from direct demand reduction measures such as voluntary conservation (e.g., driving less, turning down the thermostat) and mandatory restrictions on the availability of oil such as allocation or rationing systems.

The analysis focuses on oil replacement options that are technically and economically feasible within the next 5 years in the event of a severe oil import disruption. They include fuel switching, alternative vehicle fuels, and efficiency improvements. These options use technologies that are commercially available today, that can be manufactured in sufficient quantity and deployed within 5 years, and that require no significant changes in lifestyle or industrial mix. Some even offer additional benefits for environmental quality, economic growth, and international competitiveness.

This chapter briefly summarizes the oil disruption scenario and technology selection criteria used and identifies suitable technologies that could be deployed. Next, the oil replacement potential in the residential, commercial, electric utility, industrial, and transportation sectors is discussed. The chapter concludes with an examination of possible constraints in achieving the technical oil replacement potential, including manufacturing capability, personnel requirements, permitting requirements, and the uncertain contribution of domestic petroleum production.

Background

OTA first examined the Nation's technical potential to replace a major loss of oil imports in *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, published in September 1984.[1] That report assumed a scenario of an immediate loss of U.S. oil imports from the Persian Gulf of 3 million barrels per day (MMB/D), beginning in mid-1985 and continuing over an indefinite period of at least 5 years. The scenario represented a loss of 19 percent of the total U.S. oil supply of about 15 MMB/D, and over 60 percent of U.S. imports for 1983, the base year (see table 3-1). However, OTA found that the United States had the technical and manufacturing potential to replace 3.6 MMB/D over 5 years, as shown in table 3-2. With aggressive deployment, available energy technologies could replace about 0.6 MMB/D in the electric utility sector, and 1 MMB/D in each of the residential, commercial, industrial, and transportation sectors. Thus, in 1984, U.S. technical oil replacement capability exceeded what was then viewed as a serious import curtailment by the considerable margin of 600,000 barrels per day (B/D).

Our 1984 assessment of adequate capability to meet potential oil supply disruptions also sounded a cautionary note:

> In the longer term, declining domestic production, accompanied by an expected shift away from oil uses for stationary direct heat, will increase the Nation's vulnerability to an oil shortfall. This will occur even if all stationary uses of fuel oil are replaced by alternative fuels and conservation because the decline in domestic production is expected to occur at an even greater rate. Only by relying more heavily on coal and biomass for chemical feedstocks, increasing efficiency in natural gas use and in all modes of transportation, and producing synthetic transportation fuels in addition to accelerating the replacement and conservation of stationary uses of oil, can the Nation expect to significantly reduce its vulnerability to an oil shortfall over the next few decades.[2]

The trends pointing to decreasing flexibility in our capability to respond to oil import disruptions have continued. From 1984 to 1989 (the base year for this report), U.S. petroleum consumption has risen from

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[1] U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Springfield, VA; National Technical Information Service, September 1984), hereinafter referred to as OTA, *The Oil Replacement Capability*.

[2] OTA Report Brief, "U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability," September 1984.

Table 3-1—U.S. Oil Use by Sector, 1983 and 1989
(million barrels per day)

Sector	1983	1989
Consumption		
Residential and commercial	1.29	1.40
Industrial	3.85	4.26
Electric utilities	0.68	0.74
Transportation	9.41	10.85
Total consumption	15.23	17.24
Supply		
Domestic production[a]	10.85	10.08
Net imports	4.31	7.12
Total supplies[b]	15.23	17.24

[a] Includes crude oil, natural gas plant liquids, and processing gain.
[b] Includes stock drawdown.

SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), tables 50 and 61.

Table 3-2—U.S.Oil Replacement Technical Potential, 1984 and 1991 (million barrels per day)

Sector	1984[a]	1991[a]
Electric utilities	0.6	0.6
Residential commercial	1.0	1.0
Industrial	1.0	0.8
Transportation	1.0	0.6
Total replacement potential	3.6	2.9
Domestic oil production (decline)	0	(0.1)-(1.2)
Net replacement capability	3.6	1.7 - 2.8

[a] Individual entries may not equal total because of independent rounding.

SOURCE: Office of Technology Assessment 1991.

about 15 MMB/D to 17.2 MMB/D, as shown in table 3-1. Net oil imports have risen by almost 3 MMB/D to 7.1 MMB/D, and the share of U.S. oil needs supplied by imports has grown from 33 to over 40 percent. If an oil supply disruption comparable to that analyzed in our 1984 report were to occur today (equivalent to the loss of almost all oil exports from the Persian Gulf—or a world supply shortfall of about 15 MMB/D), the 1991 shortfall in U.S. imports could be as much as 5 MMB/D, compared with 3 MMB/D faced in 1984. However, as the following analysis shows, U.S. ability to offset lost imports by resorting to purely technical replacement strategies has shrunk. The United States no longer enjoys a comfortable margin of safety. If faced with a loss of more than one-quarter of our 1989 oil imports, U.S. technical replacement potential comes up short.

Table 3-2 compares OTA's estimates of oil replacement potential in 1984 and 1991, based on 1983 and 1989 base years, respectively. OTA estimates that available oil replacement technologies could now displace only about 2.9 MMB/D of 1989 oil use within 5 years. Moreover, this replacement potential must be further offset by the expected continuing decline in domestic oil production over the disruption period. The extent of this anticipated decline cannot be calculated with any certainty, but we estimate it to be in the range of 0.1 to 1.2 MMB/D even at the higher oil prices resulting from the crisis. The net result is that after 5 years only about 1.7 to 2.8 MMB/D of lost imports can be replaced by technical means alone. An increase in oil demand, a decline in domestic oil production, and the failure of efficiency improvements and oil replacement technologies to keep pace with consumption have combined to yield a potential net shortfall of 2.2 to 3.3 MMB/D in an import cutoff of 5 MMB/D. Thus, in the past 7 years, U.S. ability to respond to a serious oil supply disruption has declined. Some may view this as a significant factor contributing to increased oil import vulnerability.

Revised Oil Disruption Scenario and Technology Selection Criteria

The changes in energy consumption and the mix of energy sources in nontransportation sectors preclude a direct extrapolation of OTA's findings from 1984 to the present. Therefore, to reassess U.S. oil replacement capability, we updated the oil disruption scenario used in our 1984 study to reflect a 1989 base year.

Oil Disruption Scenario 1990-1995

Since 1984, total world oil use and the level of Persian Gulf exports have risen. Accordingly, to create a comparable oil disruption scenario, we have adjusted the amount of imports affected by a supply crisis and the amount of available oil stocks to reflect 1989 conditions. The other assumptions are nearly identical to those used in the 1984 study. Our 1989 scenario assumes the following:

1. An immediate oil import shortfall of 5 MMB/D occurs in 1991 and continues over an indefinite period expected to last at least 5

years. International oil-sharing agreements commit the United States to absorb one-third of world oil import losses, so that a loss of 15 MMB/D of Persian Gulf exports would mean a 5 MMB/D reduction in U.S. imports, even though the United States does not currently import that much from the Persian Gulf. The worldwide loss of production means that the U.S. shortfall under this scenario could not be made up by increasing oil imports from other countries.

2. Private and governmental commitments are made early in the disruption to replace or reduce imported oil use to the maximum extent technically and economically feasible by relying on domestic sources. Sufficient capital is available to make the required conversions.[3]
3. The strategic petroleum reserve (SPR), private stocks, and other emergency, voluntary, and mandatory conservation measures cushion the initial impacts of the shortfall. Eventually, however, the oil reserves are drawn down to zero.
4. Oil replacement technologies meeting the technical criteria (described below) are deployed over a 5-year period. Concurrently, research, development, and demonstration (RD&D) efforts on long-lead technologies are pursued so that some of these technologies can be deployed commercially beyond 1995.
5. There are no major structural changes in the output mix or behavior of the economy that could deter the 5-year deployment objective.
6. Unless otherwise noted, there are no restrictions on imports that could limit the use of technologies dependent on foreign components or materials.
7. Unless specifically noted, there are no constraints on the availability of technical personnel needed for deploying technologies.
8. There are no new special tax incentives that favor or inhibit deployment of specific technologies.

The year 1989 is used as the baseline for energy consumption, Federal policies, and applicable environmental regulations for this analysis. More recent data are included, where available, to address technological and environmental issues.

Technology Selection Criteria

The assumptions and criteria used in selecting and reevaluating the oil replacement technologies are largely the same as those used in the 1984 report. As in 1984, the technologies were selected for evaluation based on their broad potential to reduce a significant fraction of the oil consumed over a 5-year period in each of the end-use sectors while satisfying environmental standards. The following criteria were used to select oil replacement technologies for further evaluation:

1. The technology is commercially available now or is likely to be by mid-1992.
2. Individual units can be produced or installed in 2 to 3 years and deployed commercially to replace oil no later than 1995.
3. The technology has a broad potential for replacing a significant fraction—generally, more than 10,000 B/D of the oil consumed in its respective end-use sector.
4. The technology is currently among the least costly alternatives to oil in its respective end-use sector.[4]

Using these criteria we reexamined the technical replacement options identified in the 1984 study. Since the original evaluation by OTA's engineering contractors,[5] some technologies have improved slightly, but there have not been many significant advances in technology or commercial readiness. Table 3-3 identifies the candidate oil replacement options that meet the 1991 technological suitability criteria. Table 3-4 lists technologies that were excluded because they did not meet the selection criteria, in most cases because they lack enough potential for commercial deployment in 5 years. Over a longer period of time, however, some of these technologies hold some promise as alternatives to oil-using technologies and RD&D and commercialization efforts could continue while short to mid-term oil replacement options are deployed.

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[3] Alternative policy options that would aid these commitments are discussed in ch. 5 of this report.

[4] The technical criteria and evaluations are based on Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991, and comments from an OTA workshop on oil replacement technologies, Dec. 5, 1990.

[5] Gibbs & Hill, Inc., "Oil Replacement Analysis, Phase I—Selection of Technologies," OTA contractor report, April 1983; and Gibbs & Hill, Inc. "Oil Replacement Analysis, Phase II—Evaluation of Selected Technologies," OTA contractor report, August 1983.

Table 3-3—Oil Replacement Options Selected for Assessment

Sector	Oil replacement option	Technology/alternative
Electric utilities	Natural gas*	Convert; replace with combustion turbines or combined cycle units
	Nuclear	Operate completed plants
	Renewable fuels*	Biomass, municipal solid waste (MSW), geothermal, solar thermal, wind energy, small hydro
	Coal*	Convert to coal or coal slurry fuel (CSF); replace with coal gasification combined cycle (CGCC)
	Demand management	Reduce peak demand and capacity needs
Residential/ commercial	Natural gas	Use for space heating, cogeneration
	Electricity	Use for hot water, space heating and cooling
	Coal	Coal or CSF for cogeneration
	Renewable fuels	Solar, wood
	Efficiency improvement	Energy management system, emulsion fuels
Industry	Reduce refinery throughput	(A result of less imported crude to refine)
	Natural gas	Fuel switching, convert oil-fired equipment, gas-derived feedstock
	Other fuels	Fuel switching, conversion of oil-fired equipment, use coal, CSF or biomass for cogeneration, alternative feedstocks
	Process changes	Increase recycling, process optimization, waste heat recovery from process and/or waste streams
Transportation improvement	Efficiency	Improved fuel economy in vehicles, airplanes, marine fleet, and railroads
	Natural gas	Use compressed and liquefied natural gas in fleet vehicles
	Other fuels	Ethanol, methanol, liquefied petroleum gas (LPG) biomass, electric vehicles
	Traffic management	Reduce and enforce highway speed limits, use highoccupancy vehicle lanes, reduce traffic congestion to improve traffic efficiency and reduce oil consumption.
Domestic oil production	Petroleum exploration and production	Increase domestic oil supply by improved conventional and enhanced oil recovery technologies

* Includes the options of self-generation and purchases from nonutility generators.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

RESIDENTIAL AND COMMERCIAL SECTORS

In 1989 the residential and commercial sectors used 1.4 MMB/D of petroleum products.[6] Oil use was split among distillates, kerosene, residual fuel oil, and liquefied petroleum gases (LPG). (See table 3-5.) Space and water heating accounted for 98 percent of residential oil use and was also the predominant application in the commercial sector, although propane was used in many commercial establishments for cooking.

A vigorous effort to reduce oil use in the residential and commercial sectors by switching to natural gas, electricity, coal, and renewable fuels, and by speeding the adoption of efficiency improvement measures, could replace almost 1 MMB/D, or about 72 percent of 1989 petroleum consumption as shown in table 3-6. OTA's analysis identified similar potential in these sectors in 1984.

Oil Use in the Residential and Commercial Sectors

According to Department of Energy (DOE) surveys, over 17 million residential and commercial units use distillate fuel, kerosene, or LPG as their

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[6] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 61, p. 137. Hereinafter *Annual Energy Review 1989*.

Table 3-4—Oil Replacement Options Excluded From Assessment

Sector	Option	Basis for exclusion
Electric utilities	Increase imports	New imports of Canadian power above levels currently planned or projected are not included because of uncertainties over transmission system capability. Where possible, additional imports could displace oil.
	Large hydro	There are only a few suitable and environmentally acceptable new sites left in the country.[1]
	Ocean energy	Use of ocean energy in the form of temperature gradient or wave power is in the early stages of development.[1]
	Photovoltaic	Does not offer a large-scale potential. Currently 219 photovoltaic systems provide about 11 MWe with costs in excess of $ 5,000/kW. (Small PV systems for remote applications are considered elsewhere.)[2]
	Interregional power	Transmission constraints limit opportunities for increased interregional transfer of power from available non-oil based capacity.[3]
Residential/ commercial	Wind energy	Use of wind energy for buildings and in mechanical drives is not expected to make a significant contribution within 5 years.[4]
Industry	Wind energy	Use of wind energy for buildings and in mechanical drives is not expected to make a significant contribution within 5 years.[4]
	Biomass gasification	Biomass gasification will compete with direct use in industrial applications. Direct use of biomass fuels is covered as an option for industry.
	Coal gasification	Coal gasification combined cycle (CGCC) technology is used as an option for electric utilities and some industrial applications.
	Geothermal	Use of conventional geothermal in industry is limited because of the need for close proximity between the geothermal source and end-user.
	Materials and chemicals from biomass	Technology for biomass-based materials and chemicals is not yet established.
	Solar thermal	Use of solar thermal for power generation is economically more attractive than its use in industry.
Transportation	Coal in railroads and vehicles	Mild coal gasification technologies which could permit the use of clean coal char or coal-derived liquids in railroads and vehicles are in pilot plant or prototype demonstration plant phases.
Oil supply	Oil from tar sands, oil shale, and coal liquefaction	Long lead technologies that will require more than 5 years to significantly impact the domestic oil supply.

[1] *Engineering News Record*, Sept. 13, 1990, p. 26.

[2] U.S. Department of Energy, Energy Information Administration, *Power Engineering*, April 1990, p. 11.

[3] *Estimates of Short Term Petroleum Fuel Switching Capability*, DOE/EIA-0526 (Washington, DC: U.S. Government Printing Office, May 1989).

[4] Gibbs & Hill, Inc., "Oil Replacement Analysis, Phase I—The Technologies," OTA contractor report, April 1983.

[5] *Chemical Engineering & News*, Sept. 10, 1990, p. 19.

[6] Dennis Horgan, Luz International, personal communication to Renova Engineering, P.C., Sept. 19, 1990.

[7] Martin J. Hapeman, "Coal-Derived Fuels as Successful Petroleum Replacements and Unique Opportunities Offered to U.S. Railroads," paper presented at Coal—Targets of Opportunity Workshop, DCE, proceedings, Washington, DC, July 12-13, 1988.

[8] Richard A. Wolfe and Chang J. Im, "Liquid Coal—The Future Fuel for Locomotive Engines," paper presented at Coal—Targets of Opportunity Workshop, ibid.

[9] Richard A. Wolfe, Coal Research Technology Corp., personal communication to Renova Engineering, P.C., Sept. 26, 1990.

[10] Ken Markel, U.S. Department of Energy, Energy Information Administration, Morgantown, personal communication to Renova Engineering, P.C., Oct. 4, 1990.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

primary heating fuel.[7] These include some 16.4 million residential units and about 0.8 million commercial buildings. Table 3-7 and figure 3-1 summarize energy use in the residential sector by region in 1987. A map of census regions can be found in the appendix.

Table 3-8 shows selected characteristics of residential units using oil or LPG as their main heating fuel. Residential distillate and kerosene use is concentrated in the Northeast, while LPG use is largely split between the Midwest and South.

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[7] The primary source for information on energy use in the residential sector is the Residential Energy Consumption Survey conducted by DOE about every 3 years. The latest published survey data indicated that in 1987 there were over 90.5 million residential housing units or households consisting of 60.5 million single family units including both attached and detached single family houses, 5.1 million mobile homes, and 25 million residential units in multifamily buildings of 2 or more units. U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987*, part 2, regional data, DOE/EIA-0321(87)/2 (Washington, DC: U.S. Government Printing Office, January 1990), table 2, pp. 28-29. Information on commercial energy use is published in U.S. Department of Energy, Energy Information Administration, *Nonresidential Buildings Energy Consumption Survey: Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86) (Washington, DC: U.S. Government Printing Office, May 1989). Hereinafter *Commercial Buildings Consumption and Expenditures 1986*.

Table 3-5—Consumption of Petroleum Products in the Residential and Commercial Sectors, 1989
(thousand barrels per day)

Sector	Fuel oil & kerosene	Residual fuel oil	LPG	Total
Residential	563	0	294	857
Commercial	327	110	106	543
Total	890	110	400	1,400

SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 62. The total consumption was prorated among the sectors and type of fuel based on estimates in U.S. Department of Energy, Energy Information Administration, *Estimates of Short-term Petroleum Fuel Switching Capability*, DOE/EIA-0526 (Washington, DC: U.S. Government Printing Office, May 1989).

Although natural gas and electricity were the predominant heating fuels in new residential units in the 1980s,[8] the number of households burning oil products for heat increased from 15.8 million in 1981 to 16.4 million in 1987.[9] Most of the increase came in homes using kerosene or LPG. Over the same period, the number of households using distillate oil for heating declined from about 11.3 million in 1981 to 10.9 million. Between 1984 and 1987, over 600,000 homes changed from oil to gas heat.[10]

The United States has over 4 million commercial buildings, with a total floor area in excess of 56 billion square feet.[11] About 500,000 commercial buildings use fuel oil or kerosene as their main heat source, and some 250,000 use LPG.[12] Oil-heated commercial floorspace totals 8.7 billion square feet. Table 3-9 shows selected characteristics of commercial buildings heated by oil or LPG. Figure 3-2 shows commercial energy consumption by fuel and region.

Oil Replacement Options

The primary strategies for reducing oil use in the residential and commercial sectors are fuel switching and energy-efficiency measures. Most savings are

Table 3-6—Estimated Oil Replacement Potential in the Residential and Commercial Sectors
(thousand barrels per day)

Option	Residential	Commercial	Total
Natural gas	318	160	478[a]
Electricity	407	—	407[b]
Coal	—	62	62[c]
Renewable fuels and efficiency improvements	—	—	45[d]
Total	725	222	992

[a] Consists of 440,000 barrels per day (B/D) of distillate oil/kerosene and 38,000 B/D of LPG.

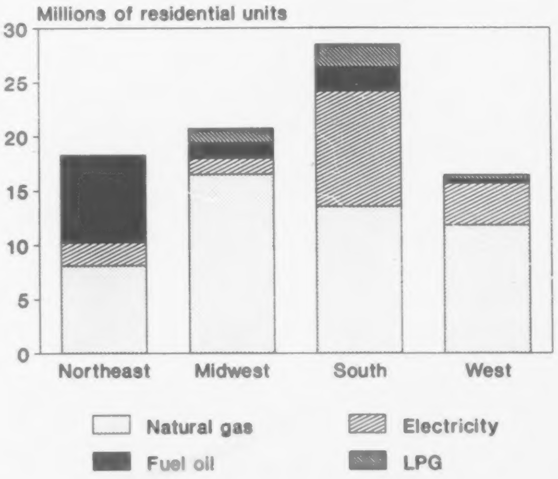
[b] Consists of 215,000 B/D of distillate oil/kerosene and 192,000 B/D of LPG.

[c] Consists of 39,000 B/D of residual oil, 16,000 B/D of LPG and 7,000 B/D of distillate oil/kerosene.

[d] Totals about 45,000 B/D savings in distillate, residual oil, kerosene, and LPG across both sectors (12,000 B/D from woodstoves and fireplaces and 33,000 B/D from various efficiency measures).

SOURCE: Office of Technology Assessment, 1991, based on Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Figure 3-1—Residential Space Heating by Region and Main Heating Source, 1987



SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987, Residential Energy Consumption Survey*, DOE/EIA-0314(87) (Washington, DC: U.S. Government Printing Office, May 1989).

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[8] American Gas Association, *Gas Facts—1988 Data*, tables 11-5 and 11-6.

[9] U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87) (Washington, DC: U.S. Government Printing Office, May 1989), table ES-1, page viii. Hereinafter referred to as *Housing Characteristics 1987*.

[10] Ibid., p. 12.

[11] *Annual Energy Review 1989*, supra note 6, table 28, p. 63.

[12] A total of 534,000 buildings reported using oil, but not all of these use it for space heating. Another 344,000 commercial buildings reported use of LPG, but only 250,000 used it for space heating. *Commercial Buildings Consumption and Expenditures 1986*, supra note 7, tables 16 and 34.

Table 3-7—Energy Use in the Residential Sector by Region, 1987

	Northeast	Midwest	South	West	Total U.S.
Residential space heating by region (millions of units)					
Main heating source					
Natural gas	8.1	16.5	13.5	11.8	49.9
Electricity	2.1	1.4	10.6	3.8	17.9
Distillates & kerosene	8.1	1.5	2.3	0.3	12.2
Liqufied petroleum gases	—	1.3	2.1	0.5	3.9
Wood	0.6	1.3	1.9	1.3	5.1
Residential fuel consumption by region (quadrillion Btus)					
Major fuels					
Natural gas	1.03	1.83	1.09	0.88	4.83
Electricity	0.44	0.61	1.22	0.48	2.76
Distillates & kerosene	0.87	0.16	0.17	0.02	1.22
Liquefied petroleum gases	0.02	0.13	0.12	0.05	0.32
Total	2.37	2.73	2.61	1.42	9.13
Wood (million cords)	8.3	12.5	13.2	8.6	42.6

SOURCES: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Housing Characteristics 1987: Residential Energy Consumption Survey*, DOE/EIA-0314(87) (Washington, DC: U.S. Government Printing Office, May 1989); and U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987, Part 2 Regional Data*, DOE/EIA-0321(87)/2 (Washington, DC: U.S. Government Printing Office, January 1990).

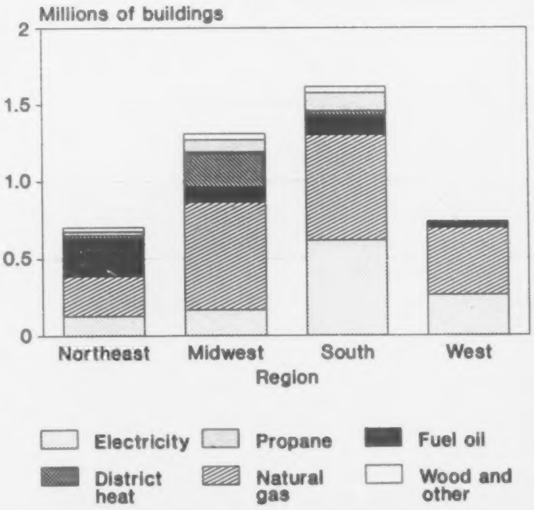
actually a combination of the two, since replacement equipment is often more energy-efficient than the old oil-burning units. We estimate that conversion to natural gas, electricity, and coal would reduce oil consumption from 1.4 MMB/D to 453,000 B/D in 5 years—132,000 B/D in residential units and 321,000 B/D in commercial buildings. This consumption could be further reduced by at least 45,000 B/D by using renewable fuels and intensifying the use of efficiency improvement measures.

Natural Gas

OTA estimates that switching to natural gas in residential and commercial buildings could displace about 478,000 B/D in residential (318,000 B/D) and commercial (160,000 B/D) buildings over 5 years. Many oil-heated residential and commercial buildings are already connected to natural gas lines or located in areas served by gas distribution networks. These buildings would be prime candidates for conversion to natural gas-fired systems.

About 3.3 million households that use distillate oil and kerosene as their main heating fuel are connected to natural gas lines, as are 0.5 million units that use

Figure 3-2—Commercial Buildings Space Heating by Fuel and Region, 1986



SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings Consumption 1986*, DOE/EIA-0246(86) (Washington, DC: U.S. Government Printing Office, September 1988), table 36.

Table 3-8—Characteristics of Households Heated by Oil and LPG
(millions of units)

Housing units	Northeast	Midwest	South	West	Total U.S.
Oil as main heating fuel					
Total households	8	1.5	2.3	0.02	12.2
Single family	4.3	1.4	1.8	0.02	7.8
Mobile home	NA	NA	0.3	NA	0.8
Multi-family	3.3	NA	NA	NA	3.5
Ownership					
Owner-occupied	5.0	1.3	1.6	0.02	8.2
Rental	3.0	0.2	0.7	NA	4.0
Location					
Urban	2.8	0.3	0.5	NA	3.7
Suburban	4.3	0.7	0.6	NA	5.7
Rural	1.0	0.6	1.2	NA	2.8
Units with secondary heat	2.4	0.8	1.5	0.02	5.0
Hot water heating fuel					
Oil	5.0	NA	NA	NA	5.2
Natural gas	1.2	NA	NA	NA	1.5
Electric	1.6	1.3	1.9	0.02	5.1
Other	0.2	NA	NA	NA	0.4
LPG as main heating fuel					
Total households	0.5	1.3	2.1	0.6	4.1
Single family	NA	1.0	1.4	0.4	2.9
Mobile home	NA	NA	NA	NA	1.2
Multi-family	NA	0.3	1.7	NA	NA
Ownership					
Owner-occupied	NA	1.1	1.7	0.5	3.4
Rental	NA	0.2	0.5	NA	0.7
Location					
Urban	NA	NA	0.3	NA	0.3
Suburban	NA	0.4	0.8	0.3	1.5
Rural	NA	0.9	1.0	0.3	2.3
Units with secondary heat	0.5	0.7	1.1	0.4	2.3
Hot water fuel					
Oil	NA	NA	NA	NA	NA
Gas	NA	NA	NA	NA	NA
Electricity	NA	0.5	1.4	0.2	2.2
Other	NA	0.8	0.7	0.4	1.9

NOTE: NA = not available, data not reported.

SOURCE: Office of Technology Assessment, 1991, from data in U.S. Department of Energy, Energy Information Administration, *Household Energy Consumption and Expenditures 1987, Part 2: Regional Data*, DOE/EIA-0321(87)/2 (Washington, DC: U.S. Government Printing Office, January 1990).

LPG.[13] Assuming that adequate natural gas supplies were available, it might be economically feasible in an oil shortfall to install the required network of small distribution lines in urban and suburban areas to connect many of the oil burning residential units without access to natural gas.[14]

We estimate that it would be feasible to convert about 6.5 million oil or LPG-heated residences to natural gas in an emergency. Switching the 3.3 million units already with gas service and connecting about 2.7 million new residential gas customers would replace about 280,000 B/D of distillate oil and kerosene. Converting all 0.5 million LPG users with gas service would save an additional 38,000 B/D.

Sixty percent of commercial buildings using fuel oil, and nearly three-quarters of the floor space, are concentrated in metropolitan areas, where it is generally easier to add gas service.[15] Of the half million commercial buildings that use distillate, kerosene, or residual oil, 10 percent, or about 0.05 million buildings, are already connected to natural gas lines.[16] Converting half of these buildings, including those with dual-fuel capacity, and adding 200,000 new commercial natural gas customers would replace an estimated 160,000 B/D. Some of these conversions might entail installing cogeneration systems to provide hot water, space conditioning, and electric power with any excess power sold to a local utility.[17] Most commercial buildings using propane are in rural areas or do not have access to natural gas distribution networks and would, therefore, not be the most likely candidates for conversion.[18]

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[13] *Housing Characteristics 1987*, supra note 9, table 21, p. 61. U.S. Department of Energy, Energy Information Administration, *Estimates of Short-Term Petroleum Fuel Switching Capability*, DOE/EIA-0526 (Washington, DC: U.S. Government Printing Office, May 1989) table 10, p. 22.

[14] Gibbs & Hill, Inc., "Oil Replacement Analysis, Phase I—Selection of Technologies," OTA contractor report, April 1983.

[15] *Commercial Buildings Consumption and Expenditures 1986*, supra note 7, table 34, p. 188.

The 478,000 B/D in natural gas replacement potential for 1989 in these sectors is slightly more than the 440,000 B/D in natural gas replacement potential estimated in our 1984 report, but involves a smaller number of units.[19] This translates into an increased demand for natural gas of about 0.96 trillion cubic feet (TCF).

Table 3-9—Characteristics of Commercial Buildings Heated by Oil or Propane From 1986 Nonresidential Buildings Energy Consumption Survey

	Oil		Propane	
	Buildings (000s)	Million sq. ft.	Buildings (000s)	Million sq. ft.
All buildings reporting use	542	11,163	351	3,362
Buildings heated by oil or propane	513	8,846	252	1,832
Location				
Northeast	252	4,515	25	331
Midwest	100	1,426	81	411
South	131	2,140	120	929
West	30	765	NA	NA
Building floorspace (000 sq. ft.)				
1-5	241	688	179	488
5-10	135	988	41	299
10-25	69	1,101	21	345
25-50	38	1,368	NA	NA
50-100	16	1,057	NA	NA
100-200	7	1,055	NA	NA
over 200	7	2,587	NA	NA
Building activity				
Assembly	71	1,387	66	456
Education	32	1,675	NA	NA
Food sales	NA	NA	NA	NA
Food service	NA	NA	NA	NA
Health care	9	737	NA	NA
Lodging	15	402	NA	NA
Mercantile/service	206	1,819	76	454
Office	69	918	NA	NA
Public order & safety	NA	NA	NA	NA
Warehouse	49	1,119	24	315
Other	18	302	NA	NA
Vacant	NA	NA	NA	NA
Buildings heated primarily by oil or propane	434	6,642	215	1,246

NOTE: NA = not available because of insufficient data.

SOURCE: Office of Technology Assessment, 1991, based on data in U.S. Department of Energy, Energy Information Administration, *Commercial Buildings Energy Consumption Survey: Commercial Buildings Characteristics 1986*, DOE/EIA-0246(86) (Washington, DC: U.S. Government Printing Office, September 1988), tables 33, 34, 35, 36, and 37.

Electricity

In a crisis, electric heat pumps and portable and fixed baseboard electric resistance heaters could replace the use of oil for comfort heating. Also, electric hot water heaters could replace oil-fired hot water heaters. The principal candidates for conversion to electricity would be some 9 million residential units that cannot be converted economically to natural gas because of the lack of a gas supply infrastructure.[20] These include 5.4 million units using distillate oil or kerosene and 3.6 million units using LPG. Converting three-quarters of these homes, a total of about 6.75 million units, to electricity could replace about 407,000 B/D of oil over a 5-year period. This changeover would increase the number of electrically heated homes significantly (i.e., by about one-third).[21]

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[16] U.S. Department of Energy, Energy Information Administration, *Estimates of Short-Term Petroleum Fuel Switching Capability*, DOE/EIA-0526 (Washington, DC: U.S. Government Printing Office, May 1989) (Hereinafter *Short-Term Petroleum Fuel Switching*) table 12, p. 26. According to DOE, these buildings account for half of all oil-heated commercial floor space, but their oil consumption in 1983 was only 17,000 bbls/day, so it is unclear how much oil their conversion will actually displace.

[17] More than 600 cogeneration systems have been installed in commercial facilities through 1987. The commercial sector, in general, has a large untapped cogeneration potential of 40,000 MW, according to an analysis by Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference? Volume 2, Part 1 of 3, End-Use Technology*, ORNL-6541/V2/P1, December 1989, p. 50.

[18] *Commercial Buildings Consumption and Expenditures 1986*, supra note 7, table 18, pp. 90-91.

[19] The 1984 report estimated that 80 percent of urban households, 7 million units, and 80 percent of commercial buildings could be converted to natural gas, OTA, *The Oil Replacement Capability*, supra note 1.

[20] *Housing Characteristics 1987*, supra note 9, table 21, p. 61.

[21] Electric heat was used by about 20 percent of homes and 30 percent of commercial buildings in 1987. According to U.S. Department of Energy (DOE) survey data, 17.9 million residences were electrically heated. *Housing Characteristics 1987*, supra note 9, footnote 9, p. 12. Over 90 percent of the electrically heated homes were located in areas without access to natural gas. By 1987, about half of all new homes used electric heat, often in the form of a heat pump that could be used for both heating and cooling. Almost 1.2 million commercial buildings used electric heat, about 60 percent of these in the South.

About 2.5 million of these oil to electric conversions would be in households using LPG. Many of these buildings are located in rural areas, and some could require upgrading of service and improvements to the local electric transmission and distribution systems to accommodate the increased load.[22]

Although electric space and water heating is common in commercial buildings, we have generally not assumed any large-scale replacement of oil heat with electricity in commercial buildings because for many it would not be the least expensive option. However, in a crisis, many small commercial buildings that use propane could opt for electric heat.

A share of these oil to electric conversions would occur in colder regions, where electric heat pumps alone could not maintain comfort in extreme cold. Below 20 to 30°F, electric resistance heat is more effective, and heat pumps are often equipped with resistance heat for low-temperature operation. If one-third of the heat pump conversions had to operate on electric resistance heating at the same time, it would increase the winter peak load in these regions by as much as 11,000 megawatts (MW).[23] Although capacity seems ample to absorb such an increase, some local systems may find capacity margins strained.[24] There is, however, as we noted in our 1984 report, a sticky technical issue of whether replacing oil heat with heat pumps in some very cold areas would effectively displace oil, especially if utilities must burn oil to generate the electricity.

Electric heat pumps typically have efficiencies (heat delivered to the inside air divided by the energy used to run the device) of over 100 percent, and some as high as 200 percent.[25] In contrast, oil heat has an efficiency of about 65 percent. This means that an efficient heat pump requires about one-third as much energy (in the form of electricity) as an oil furnace requires (in the form of oil) to deliver the same amount of heat. This makes the heat pump an attractive alternative for replacing oil, but only if the electricity is not generated from oil. If, however, the electricity is generated with oil, for which the efficiency of converting fuel to electricity is about 32 percent, this potential oil replacement is lost, since it would require at least as much oil to produce the electricity as would be saved by the heat pump. Consequently, in terms of oil replacement, heat pumps are attractive only where marginal electricity is generated from fuels other than oil.[26]

The Northeast is among the regions where some oil use for electric generation is most likely to continue after an oil shortfall. That region's cold winters reduce the efficiency of the heat pumps creating the possibility that burning oil to produce electricity for heat pumps could lead to a net increase in oil consumption; and it would be, at best, a questionable strategy to promote heat pumps as a means of displacing oil there.[27] Nonoil generating capacity additions in the Northeast region since 1984 have somewhat improved the potential for using electric heat to backout oil for some residential users.

Recent advances have made heat pump technology more energy-efficient, economical, and practical for commercial and residential installations in colder climates.[28] A dual-fuel, electric-gas heat pump jointly developed by the Lenox Corp. and the Electric Power Research Institute (EPRI) heats with natural gas in extreme weather conditions.[29] Electronic controls monitor the unit and switch to the most economical fuel for prevailing temperatures. The units are targeted to replace existing gas furnace-electric cooling combination systems common in commercial buildings, but would be suitable for replacing oil units. The heat pump is commercially available in the 7.5- to 10-ton range, which is appropriate for commercial buildings of 2,000 to 4,000 square feet, including many stores, restaurants, and small office buildings. Initial commercial installations have resulted in savings of up to 41 percent on monthly utility bills. This combination could make conversion from oil to gas electric systems an attractive alternative for commercial buildings, but we have not included such conversions in our oil savings. The most likely candidates are already in the target population for oil to gas switching in the commercial sector.

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[22] OTA, *The Oil Replacement Capability,* supra note 1.

[23] Renova Engineering, P.C., supra note 4.

[24] Planned winter capacity resources in the Northeast and Mid-Atlantic states in 1995 are projected to exceed the projected winter peak demand with projected capacity margins of 26.9 percent in the Northeast Power Coordinating Council (NPCC) region and 30.2 percent in the Mid-Atlantic Area Council. North American Electric Reliability Council, *1990 Electricity Supply & Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990). With intensified deployment of electric heat pumps, the capacity margins could be squeezed. A detailed study is necessary to evaluate the regional breakdown of this decline in margin and its potential impact on the capacity needs and reliability of local electric utilities.

[25] Heat pumps equipped with resistance heat and/or air-conditioning capability generally have somewhat lower efficiencies.

[26] OTA, *Oil Replacement Capability,* supra note 1, pp. 60-61.

[27] OTA, *The Oil Replacement Capability,* supra note 1, pp. 59-60.

[28] Electric Power Research Institute (EPRI) and Carrier Corp. have jointly developed an advanced unitary heat pump that features variable speed compressor, variable speed indoor fan, single speed outdoor fan, and integrated water heating. Two and three ton units are commercially available. A. Lannus, "Residential Program: Current Research Projects," Electric Power Research Institute, January 1990.

[29] Morton Blatt, Electric Power Research Institute, personal communication to Renova Engineering, P.C., OTA contractor, Oct. 12, 1990; and "Heat Pumps: Developing the Dual-Fuel Option," *EPRI Journal,* December 1990, pp. 23-27.

Coal

The large commercial buildings that are not converted to natural gas could be candidates for conversion to coal or coal slurry fuel (CSF), a coal-water mixture that contains up to 70 percent finely ground coal and can be pumped, transported, and stored much like heavy oil. Because of their energy intensity and large size, hospitals, nursing homes, educational institutions, hotels, and motels provide the most promising opportunities for installing coal-based cogeneration systems to provide heat, hot water, and electric power.[30] A number of such facilities have already installed coal-fired cogeneration systems to replace oil.[31]

The potential candidates for coal-based systems can be divided in three groups:[32]

- Group I—100,000 buildings with large boiler systems that currently use 110,000 B/D of resid.
- Group II—300,000 buildings mostly in rural areas that currently use 106,000 B/D LPG.
- Group III—200,000 other commercial buildings that use 160,000 B/D of distillate oil and kerosene.

Converting to coal is not a small task and the decision would be determined by individual site characteristics. The site must be able to accommodate fuel storage, handling, and waste storage or disposal facilities, in addition to the actual boilers, generators, and pollution control equipment. Group I buildings offer the best potential for coal conversion.

OTA has assumed conversion rates of 35, 15, and 5 percent for Groups I, II, and III respectively. Thus, conversion of 88,000 commercial buildings to burn coal could replace about 62,000 B/D of oil.

Renewable Energy Sources

Increased use of wood as a primary or secondary heating source could provide a handy short-term means of cutting residential oil use in some areas.[33] The number of U.S. households that use wood as a primary heating fuel has declined from 6.5 million in 1984 to 5.1 million in 1987.[34] Over 19 million households have woodburning stoves or fireplaces as a secondary heat source, including 3.7 million homes primarily heated by oil or LPG.[35] If 250,000 households converted to wood in a crisis, it would save about 12,000 B/D.

About half of oil heated homes use oil for water heating as well. Some of these homes may be appropriate candidates for solar water heating. Solar hot water heaters could replace, on average, about 300 gallons per year of oil per household.[36] The relatively high cost of solar equipment and limited insolation may limit the use of solar energy in colder regions, however.[37]

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[30] A. John Rezalyn et al., "Site Specific Coal Energy System Assessments," paper presented at Coal—Targets of Opportunity Workshop, U.S. Department of Energy, July 12-13, 1988, Washington, DC.

[31] For example, micronized coal cogeneration plants have been installed at Missouri and Ohio hospital complexes. Micronized coal is pulverized to a fineness of 15 to 20 microns, more than 10 times finer than conventional pulverized coal and its burning characteristics are similar to oil or gas making it an attractive option for modifications of existing plants. Tom Elliott, "Latest Micronized Coal Mills Consume Less Energy, Cost Less," *Power,* July 1990, pp. 39, 42-44.

[32] Renova Engineering, P.C., supra note 23, p. 39.

[33] OTA, *The Oil Replacement Capability,* supra note 1.

[34] *Housing Characteristics 1987,* supra note 9, table ES-1, p. viii.

[35] *Housing Characteristics 1987,* supra note 9, table 21.

[36] Michael Winerip, "A Gulf Question: Don't You Wish You Had Solar?" *The New York Times,* Tuesday, Sept. 25, 1990.

[37] Use of solar heating to replace oil use indirectly might be an attractive option in areas of the Southeast, such as Florida, as a means of reducing demand for oil-fired electricity.

Efficiency Measures

Our 1984 report estimated that residential and commercial oil use could be reduced on average by 25 percent per unit through a combination of weatherization and burner efficiency upgrades.[38] The residential sector is highly flexible in its ability to conserve energy and to respond to fuel price changes.[39] A significant number of households have already adopted one or more conservation measures in response to earlier oil supply crises, but some incremental efficiency savings likely remain.[40]

Replacing inefficient oil burners with more efficient ones can reduce oil consumption by as much as 25 percent.[41] Old oil burners typically have conversion efficiencies of 65 percent, at best. Newer burners can achieve efficiencies of 85 percent or more. For example, in one study in Michigan, retrofitting oil furnaces with flame retention burners, which improve oil and air mixing and thus burn fuel more completely than do conventional burners, yielded average fuel savings of 25 percent at installation costs of $570 per unit, or $0.27 per gallon of oil saved.[42]

Insulating hot water tanks and pipes and improving the efficiency of the area heated by adding ceiling and wall insulation, storm windows, caulking, and weatherstripping can also have paybacks in reduced oil consumption and lower energy costs.

The commercial sector could adopt similar options to reduce oil use. For example, almost two-thirds of commercial oil users surveyed by DOE reported adoption of building energy conservation measures.[43] Most cited preventive maintenance, ceiling and wall insulation, and weatherstripping and caulking, but the data did not indicate whether these measured had captured all of the potential energy savings available. Few respondents had adopted more sophisticated measures such as time clock thermostats, waste heat recovery, or energy management control systems. More than 85 percent of these buildings had never had an energy audit.

It is likely that there remains incremental energy conservation potential in the commercial sector as well. Improved operations and maintenance practices could optimize steam or hot water generation efficiency, reduce thermal losses in distribution piping, and improve system controls for conserving thermal energy.

OTA's earlier analysis found that replacing or retrofitting commercial equipment with more efficient burners also offers average fuel savings of 20 to 25 percent per unit.[44] Using oil-water emulsion fuels in residual oil-fired boilers can reduce oil consumption by 5 to 10 percent.[45]

We estimate that use of various energy conservation and efficiency improvements in existing equipment and buildings could save about 33,000 B/D additionally.

Deployment Considerations

Table 3-6 summarizes the breakdown of the estimated 1 MMB/D of oil that could be replaced in the residential and commercial sectors by the various options assessed above. The major concerns in meeting these oil replacement estimates involve: 1) the adequacy of the manufacturing and installation capability for new or retrofitted equipment, and 2) the availability of substitute energy resources—namely, natural gas and electricity. Neither of these concerns are expected to be constraints in achieving oil replacement targets if aggressive private and government efforts are made.

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[38] OTA, *The Oil Replacement Capability*, supra note 1, p. 104.

[39] U.S. Department of Energy, "Energy Conservation Trends-Understanding the Factors that Affect Conservation Gains in the U.S. Economy," DOE/PE-0092, September, 1989. and U.S. Department of Energy, *National Energy Strategy, Interim Report, a Compilation of Public Comments*, DOE/S-0066P, April 1990.

[40] *Housing Characteristics 1987*, supra note 9, table 33 shows installation of various weatherization measures in housing units and indicates there still are units in cold climates without, for example, storm doors and windows, or adequate insulation in ceilings, walls, and floors.

[41] Thomas J. Lueck, "Taking a New Look at Energy Saving," *The New York Times*, Sunday, Sept. 16, 1990.

[42] Sam Cohen, "Measured Savings: Fifty Million Retrofits Later," *Home Energy*, May/June 1990, pp. 11-16, at p. 16.

[43] *Commercial Buildings Consumption and Expenditures 1986*, supra note 7, table 34.

[44] OTA, *The Oil Replacement Capability*, supra note 1.

[45] John Dooher, Adelphi University, personal communication to Renova Engineering, P.C., OTA contractor, Oct. 3, 1990 and information received from Petrofirm, Inc.

Conversions to natural gas would involve 6.75 million residential and commercial units over 5 years. In 1988 manufacturers shipped 2.3 million gas-fired warm air furnaces and boilers.[46] The Gas Research Institute (GRI) has projected that gas-fired replacement systems will range between 2 and 2.8 million units per year between 1988 and 2010.[47] At this level, manufacturing capacity for replacement boilers is not expected to be a constraint.[48]

The manufacturing capacity for oil-to-gas conversion burners has declined by about 50 percent compared with the peak period of 1979-81.[49] Residential gas heating conversions peaked in 1980 at 583,000, of which 85 percent were oil-to-gas conversions.[50] In recent years, the annual conversions to natural gas have settled at 150,000 to 200,000, with an increasing share of conversions from electricity to natural gas.[51] Assuming a 70-percent capacity utilization in 1980, the current manufacturing capacity for oil-to-gas conversion burners is thus estimated to be only 350,000 units per year. This major constraint could be overcome by shifting some of the new burner manufacturing capacity to the production of conversion burners during a crisis.

We have assumed, that based on our earlier analysis, there will not be any major manufacturing constraints in converting to electricity.[52]

Small, modular, pulverized, or micronized coal-fired cogenerating units can be designed, manufactured, and installed in 14 months, on average.[53] Conversion to CSF will take 2 to 3 years because of the need to erect CSF plants and obtain the necessary environmental permits relatively smoothly over a permitting process of 12 to 18 months.[54]

Natural gas availability and electric generation capability considerations are addressed more fully later in this chapter. While some natural gas and electricity supply constraints are possible in the Northeast and Mid-Atlantic States that might limit fuel switching, we believe that these are not insurmountable. The potential constraints on natural gas conversions may in fact be less than they were in our 1984 analysis because of more abundant supplies of natural gas and planned new pipeline capacity.

Table 3-10—Deployment Schedule for Oil Replacement Technologies in the Residential and Commercial Sectors (thousand barrels per day)

	Fuel switching option				
Year	Gas[a]	Elect.[a]	Coal[b]	Efficiency/ renew.[c]	Total
1991	96	81	0	15	192
1992	191	163	0	30	384
1993	287	244	0	45	576
1994	382	326	31	45	784
1995	478	407	62	45	992

[a] Assumes uniform deployment over 5 years.
[b] Assumes oil replacement in the last 2 years.
[c] Assumes uniform deployment in the first 3 years.

SOURCE: Office of Technology Assessment, 1991, based on Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Without these constraints, the conversion to natural gas and electricity could occur uniformly over the assumed 5-year period. The use of renewable fuels and efficiency improvement measures are expected to show results early in the first 3 years. Coal replacements of oil would begin only in the last 2 years. A deployment schedule based on such a scenario is shown in table 3-10.

The estimated investment costs for the various oil replacement options are shown in table 3-11. The table shows the range in cost in thousands of dollars per barrel of oil per day replaced for technologies considered. If all the identified residential and commercial oil replacement technologies were deployed, we estimate the total cost to be about $97 billion. The

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[46] American Gas Association, *Gas Facts—1988 Data*, table 11-2.

[47] Gas Research Institute, "1990-1994 Research and Development Plan and 1990 Research and Development Program," 1989.

[48] Messrs Eisenbeis and Newton, Burnham America, Inc., personal communication to Renova Engineering, P.C., OTA contractor, Oct. 3, 1990. Ed Anderson, Brooklyn Union Gas Co., personal communication to Renova Engineering, P.C., OTA contractor, Oct. 4, 1990.

[49] Terry Adams, Adams Manufacturing, Inc., personal communication to Renova Engineering, P.C., OTA contractor, Oct. 3, 1990.

[50] American Gas Association, "The Outlook for Gas Energy Demand: 1990-2010," May 1990.

[51] Ibid.

[52] OTA, *The Oil Replacement Capability*, supra note 1.

[53] Elliott, supra note 31.

[54] Ed McHale, Atlantic Research Corp., personal communication to Renova Engineering, OTA contractor, Sept. 19, 1990. Clay Smith, Otisca Industries, Inc., personal communication to Renova Engineering, OTA contractor, Oct. 3, 1990.

Table 3-11—Estimated Investment Costs for Oil Replacement Technologies in the Residential and Commercial Sectors
(approximate investment cost in thousand 1990 dollars per barrel per day of oil replaced)

Option	$000 per B/D replaced		Remarks [a]
	Minimum	Maximum	
Natural gas	25	38	Minimum—conversion of homes at $800 for a 160,000 Btu/hr burner. Maximum—conversion of commercial buildings at $25,000 for a 25 MM Btu/hr burner.[b]
	47	111	Minimum—replacement boiler for homes at $2,000 for a 160,000 Btu/hr unit. Maximum—new boiler for commercial buildings at $75,000 for a 25 MM Btu/hr unit.
Electricity	28	113	Electric resistance heat at $500 for heaters plus hot water heater at $1,000 per household.[c] Electric heat pumps at $5,000 plus hot water heater at $1,000 per household.
Coal	445	667	Assumes CSF-fired boiler cost at four to six times that of a gas-fired boiler in commercial buildings.[d]
Renewable fuels & efficiency improvements	147	179	Minimum—10% oil savings in a commercial building with a $10,000 Energy Management System.[e] Maximum—in a household, 300 gal./yr saving from a solar hot water heater at $3,500.

KEY: CSF = coal slurry fuel

[a] Fuel use estimated at 0.053 B/D per residence and 0.679 B/D per commercial building.

[b] Conversion burner and replacement boiler costs from Eisenbeis and Newton, Burnham America, Inc., personal communication to Renova Engineering, P.C., Oct. 4, 1990. Terry Adams, Adams Manufacturing, Inc., personal communication to Renova Engineering, P.C., Oct. 3, 1990. Assumes $500 for piping changes in all cases.

[c] Cost data from Gibbs & Hill, Inc.,"Oil Replacement Analysis, Phase I—Selection of Technologies," OTA contractor report, April 1983.

[d] Cost of a 25 MM Btu/hr gas-fired boiler at $75,000, Eisenbeis and Newton, Burnham America, Inc., personal communication to Renova Engineering, P.C., Oct. 4, 1990, plus $500 for piping changes.

[e] Solar hot water heater data from Michael Winerip, "A Gulf Question: Don't You Wish You Had Solar?" *The New York Times*, Sept. 25, 1990.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

investment costs for individual technologies per B/D replaced range from $25,000 B/D replaced for converting residential oil burners to natural gas to $667,000 B/D replaced for installation of a CSF boiler in a commercial building.

ELECTRIC UTILITY SECTOR

Electric utilities burned about 731,000 B/D of petroleum products to generate electric power in 1989.[55] Heavy oils (mainly No. 6 residual fuel oil) accounted for most of this demand, or 661,000 B/D (see table 3-12). Use of distillates was relatively small: about 70,000 B/D of light oils or distillates (No. 2 fuel oil), primarily for startup and flame stabilization in conventional steam plants or as a backup fuel in combustion turbines and combined-cycle plants. Oil-fired generation of electricity represents less than 5 percent of U.S. oil consumption and only about 4 percent of net generation. Utility oil use remains concentrated in the Northeast and Mid-Atlantic States, California, Florida, and Hawaii as shown in figure 3-3. These regions together accounted for about 95 percent of all utility oil consumption in 1989. Oil-fired generating

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[55] *Annual Energy Review 1989*, supra note 6, table 62, p. 139.

Table 3-12—1989 Oil and Gas-Based Electric Generation and Fuel Consumption by Region
(summer generation capacity in 1,000 MW[a])

		Dual fuel			Generation, billion kWh		Fuel used	
Federal region	Oil[b]	Coal/oil[c]	Gas/oil[c]	Gas[b]	Oil	Gas	Oil MB/D[d]	Gas million cubic feet/day[e]
1 New England	7.0	2.0	2.0	0.0	37.0	5.2	155	149
2 New York/New Jersey	8.0	0.4	9.2	0.0	46.7	21.8	195	624
3 Middle-Atlantic	5.7	3.9	2.9	0.0	21.9	3.1	91	89
4 South-Atlantic	5.8	3.6	11.7	0.6	28.0	21.8	117	624
5 Midwest	6.1	7.5	0.8	0.2	3.1	1.8	13	52
6 Southwest	0.0	2.8	47.7	8.4	2.8	145.0	12	4,152
7 Central	0.0	4.4	2.2	0.4	0.3	1.9	1	54
8 North Central	0.0	2.4	0.5	0.0	0.2	0.7	1	20
9 West	1.2	3.0	23.2	0.5	17.8	58.6	74	1,678
10 Northwest	0.1	0.0	0.0	0.0	0.5	4.9	2	140
Total	33.9	30.0	100.2	10.1	158.3	264.8	661	7,583

[a] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, April 1990;* DOE/EIA-035(90/04) (Washington, DC: U.S. Government Printing Office, July 1990).

[b] Excludes units having dual fuel capability.

[c] Includes units that cannot burn either fuel continuously.

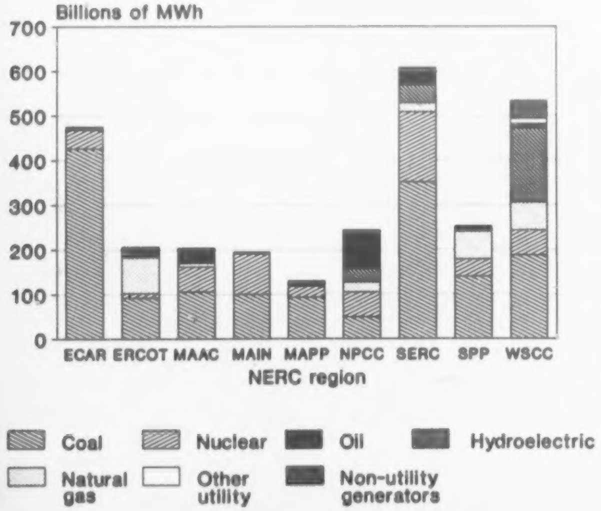
[d] Regional oil-based generation estimated based on 1989 utilities consumption of 241.4 million barrels of heavy oil. This amount was prorated for each region using oil-based generation reported in U.S. Department of Energy, Energy Information Administration, "Petroleum Fuel-Switching Capability in the Electric Utility Industry," *Electric Power Monthly: June 1990,* DOE/EIA-0226(90/06) (Washington, DC: U.S. Government Printing Office, September 1990).

[e] Reference a indicates that in 1989 utilities consumed 2,768 billion cubic feet of natural gas. This amount was prorated for each region using gas-based generation reported.

KEY: MW = megawatt; kWh = kilowatt hour; MB/D = thousand barrels per day.

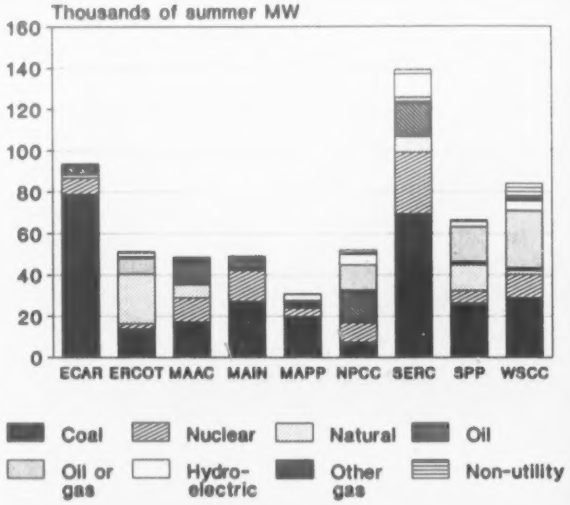
SOURCE: Office of Technology Assessment ,1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Figure 3-3—Generation of Electricity by Electric Utilities by Region and Energy Source, 1989



SOURCE: Office of Technology Assessment, 1991, from data in North American Electric Reliability Council, *1990 Electricity Supply and Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990), app. B.

Figure 3-4—Electric Utility Generating Capacity by Region and Energy Source, 1989



SOURCE: Office of Technology Assessment, 1991, from data in North American Electric Reliability Council, *1990 Electricity Supply and Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990), app. A.

Table 3-13—Estimated Oil Replacement Potential in the Electric Utility Sector
(oil replacement potential—thousand barrels per day)

Federal region	Fuel Switching Option				Demand management[e]
	Gas[a]	Nuclear[b]	Renewables[c]	Coal[d]	
1 New England	9	22	95*	360*	15*
2 New York/New Jersey	35	0			
3 Middle-Atlantic	4	22			
4 South-Atlantic	14	0			
5 Midwest	7	0			
6 Southwest	4	0			
7 Central	0	0			
8 North Central	0	0			
9 West	12	0			
10 Northwest	0	0			
Subtotal	85	44	95*	360*	15*
Total (all sources)	599				

NOTE: *oil savings not allocated by region.

[a] U.S. Department of Energy, Energy Information Administration, "Petroleum Fuel-Switching Capability in the Electric Utility Industry," *Electric Power Monthly: June 1990*, DOE/EIA-0226(90/06) (Washington, DC: U.S. Government Printing Office, September 1990).

[b] Excludes the 809 MW Shoreham Unit in Region 2, if included, an additional 15,000 B/D could be displaced.

[c] Based on deploying 5,000 MW of renewable fuel-based nonutility generation (NUG) capacity in 5 years.

[d] Based on a combination of four options—coal or CSF in coal/oil capable units, CSF in oil-only capable units, purchases from coal-based NUG plants, and coal gasification combined cycle plants.

[e] Based on 4,000 MW from demand management programs.

capacity is less concentrated geographically. As shown in figure 3-4, oil-based generating capacity (including oil/gas dual-fuel units) constitutes a significant share of the resource base in all regions. (Maps of Federal and NERC regions can be found in the appendix.)

Oil Replacement Options

The largest potential for oil replacement in the utility sector is for reducing the use of heavy oil, which constitutes most of utility oil use. Light oil consumption is not a significant factor, and most such uses cannot be easily replaced.[56]

OTA estimates that it is technically feasible to replace about 600,000 B/D, or over 80 percent of utility oil use (90 percent of residual oil use), within 5 years by fuel switching in dual-fuel capable units or by shifting generating loads to non-oil units. This potential has remained constant since 1984 even as non-oil generating capacity and fuel-switching capabilities have increased, because growing demand for electricity and narrow capacity margins have made reliance on oil-fired generation essential and the lower cost of gas and other fuels relative to oil (except for a brief period in 1986-87) have already induced many utilities to burn gas or coal in dual-fuel units.

Replacing oil could be accomplished by using existing equipment, completing planned capacity now under construction, converting existing equipment to other fuels, and installing new non-oil generating capacity.[57] These efforts could be facilitated by and additional savings could be gained through demand-side efforts, but these savings are not broken out separately in our estimates. Table 3-13 shows the estimated oil replacement capability in the utility sector in 1989.

We have included the oil replacement potential of new nuclear power plants that came on line in 1990 in regions where there is heavy oil use. We also note the planned addition of new utility and nonutility generating capacity in these regions in 1991-94, but since these plants are not yet complete, we do not include them specifically in our totals. These capacity additions are, however, implicitly included in our estimates of oil replacement potential since they are part of utility resource planning.

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[56] Nevertheless, there may be some potential to reduce the use of light oil. For example, tests are underway in coal-fired steam plants to evaluate the feasibility of using micronized coal in place of light oil for plant startup. Elliott, supra note 31. Similarly, utilities could switch to natural gas for firing turbines, wherever possible.

[57] Electricity demand growth and capacity margins are key variables in the ability to shift oil-fired generation to other plants.

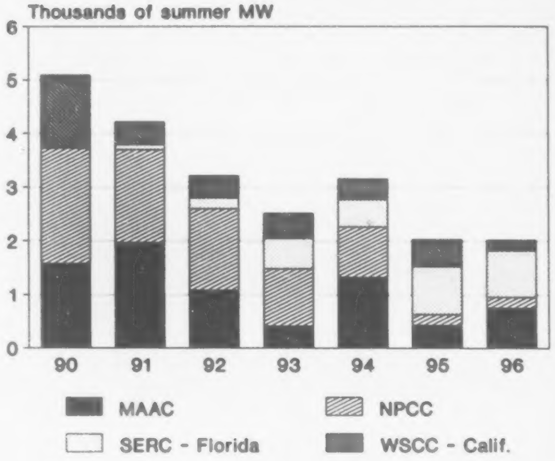
Natural Gas

Utilities can substitute natural gas for oil in three ways: by burning natural gas in existing oil/gas, dual-fuel units, by shifting load to existing gas-only units, and by shifting to new gas-fired capacity either in converted oil units or newly constructed gas units.

About 100,200 MW of existing capacity is classified as dual fuel—gas/oil capable units—and about two-thirds of these units can burn gas continuously.[58] According to DOE, electric utilities can thus replace about 85,000 B/D of oil in less than 30 days by increasing natural gas-based generation in these units.[59] The fuel switching potential, however, is highly dependent on the seasonal availability of natural gas, and thus ranges from an average of 54,000 B/D in the second quarter to an average of 117,000 B/D in the fourth quarter. This appears to be the minimum potential that could be achieved almost immediately on an annual average and would not require any significant alterations of equipment.

Additional displacement of oil with new or retrofitted natural gas units within 5 years is also feasible. The American Gas Association has estimated that natural gas could replace approximately 50,000 B/D of oil for power generation boilers in the very short term and 300,000 B/D after 5 years.[60] A Gas Research Institute analysis estimates that natural gas could displace 95,000 B/D of oil in electric power generation in the short term (2 years or less) and 280,000 B/D over the longer term (10 years) under somewhat different supply disruption and policy scenarios.[61] Because of uncertainties over the availability of additional natural gas supplies in oil dependent regions, OTA has not included a higher estimate of gas replacement potential. If gas supplies are available, we expect that additions of new gas generating capability will reduce the use of coal to replace oil.

Figure 3-5—Planned New Non-Oil Capacity Additions in 1990 to 1995 in Oil Dependent NERC Regions



SOURCE: Office of Technology Assessment, 1991, from data in North American Electric Reliability Council, *1990 Electricity Supply and Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990), app. D.

Utilities and independent power producers (also known as nonutility generators, or "NUGs") have announced plans to construct and operate new natural gas-fired generating units. According to figures published by the North American Electric Reliability Council (NERC), about 24,000 MW of gas-fired generating units are planned to come on line in 1991 through 1999.[62] See figure 3-5. It is not certain how much of this planned capacity will be built on schedule and whether there is access to adequate natural gas supplies. It is clear, however, that utilities view new natural gas capacity as an important and economic option in the years ahead.

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[58] Jeffrey Jones, "Petroleum Fuel-Switching Capability in the Electric Utility Industry," in U.S. Department of Energy, Energy Information Administration, *Electric Power Monthly: June 1990,* DOE/EIA-0226(90/06) (Washington, DC: U.S. Government Printing Office, September 1990), table FE4, p. 4.

[59] Ibid., p. 2.

[60] American Gas Association, "The Role of Natural Gas in Offsetting Oil," A.G.A. Planning & Analysis Group, Mar. 21, 1991, p. 9. Interstate Natural Gas Association of America, "Displacing Imported Oil With Natural Gas," Issue Analysis, Report No. 91-1, Rate and Policy Analysis Department, May 1991.

[61] Paul D. Holtberg and David O. Webb, 'The Potential for Natural Gas To Displace Oil in Response to the Middle East Crisis and the Implications for the GRI R&D Program," Gas Research Insights, Gas Research Institute, Chicago, IL, November 1990. Natural gas offers substantial promise for utilities in the 1990s; however, utility analysts believe that uncertainties over future natural gas prices and deliverability pose some financial and reliability risks for utilities that must be addressed in resource planning. See Strategic Decisions Group, *Natural Gas for Electric Power Generation: Strategic Issues, Risks, and Opportunities*, EPRI P-6820 (Palo Alto, CA: Electric Power Research Institute, 1990); and Putnam, Hayes & Bartlett, Inc. and Energy Ventures Analysis, *Fuel Switching and Gas Market Risks*, EPRI P-6822, vols. 1 & 2, final report (Palo Alto, CA: Electric Power Research Institute, July 1990).

[62] See North American Electric Reliability Council, *1990 Electricity Supply & Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, December 1990) table 29, p. 48.

One of the largest new facilities in an oil dependent-region is the Ocean States Power Project (two 250-MW combined-cycle plants) under construction in Rhode Island. The first 250-MW gas-fired unit began operation in December 1990.[63] Ocean States is a "hybrid" independent power producer that includes several utility affiliates as partners.[64] The project will be dispatched as part of the New England Power Pool and will likely serve as baseload capacity. Gas supplies for the project will be under a contract for firm deliveries and one of its joint venture participants is an affiliate of its gas supplier.

Nuclear Power

Three nuclear power plants began commercial operation in 1990: the 1,150 MW Limerick Unit 2 in Pennsylvania, the 1,150 MW Seabrook in New Hampshire, and the 1,150 MW Comanche Peak Unit 1 in Texas (an area where oil consumption is not a major concern).[65] The Limerick and Seabrook units with a total of 2,300 MW are in areas that are heavily reliant on oil-fired generation and together could replace about 44,000 B/D in intermediate loads.[66]

In addition, the 809 MW Shoreham Unit in New York has been completed but has not proceeded to commercial operation.[67] Concerns over the feasibility of emergency evacuation plans led State and local officials to negotiate a takeover of the plant from Long Island Lighting Co. Under the takeover plans, the Shoreham Plant will be decommissioned. It is estimated that the Shoreham Plant might have displaced about 14,000 B/D of oil. Secretary of Energy Watkins has opposed decommissioning Shoreham and has joined litigation to stall the plant's dismantling.[68] No other nuclear units are scheduled to come on line before 1995 in the oil-dependent regions.

Renewable Energy

In 1989, renewable energy sources, including hydroelectric, geothermal, wood, solar, municipal solid waste (MSW), and wind, provided just under 10 percent of net electric generation.[69] Many of these facilities were built and operated by NUGs. In 1989 about 2,500 NUG plants were in operation with an installed capacity of about 28,000 MW. About 60 percent of these plants used renewable fuels and together had an installed capacity of about 11,000 MW, or about 40 percent of the total NUG capacity.[70] Various forecasts indicate a significant growth during the 1990s in the NUG capacity, including capacity based on renewable fuels. For example, in 1989 DOE estimated an addition of 4,000 MW of renewable fuels-based NUG capacity between 1990 and 1995. And, based on its database, RCG/Hagler, Baily Inc., has recently projected a 7,400-MW addition through 1996.

Hydroelectric Power—According to NERC, about 1,300 MW of new hydroelectric generation is scheduled to come on line between 1991 and 1999.[71]

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[63] "Ocean State Power Comes on Early," *Energy Daily*, Jan. 15, 1991, p. 6.

[64] See Congress of the United States, Office of Technology Assessment, *Electric Power Wheeling and Dealing: Technological Considerations for Increasing Competition*, OTA-E-409 (Washington DC: U.S. Government Printing Office, May 1989), p. 129, for further discussion of the Ocean State Project.

[65] Mona Reynolds, "Utilities Bring a Variety of New Plants on Line," *Power Engineering*, p. 23, April 1990. Douglas J. Smith, "Non-Utility Power Production Increases," *Power Engineering*, page 13, July 1990. Douglas J. Smith, *Power Engineering*, personal communication to Renova Engineering, Oct. 4, 1990.

[66] This potential is based on displacing an equivalent oil-based capacity operating at a 50 percent capacity factor (intermediate duty) with an average heat rate of 10,000 Btu/kWh. The heat content of residual oil is assumed to be 6.3 million Btu/bbl.

[67] North American Electric Reliability Council, *Electric Supply & Demand 1989-1998* (Princeton, NJ: North American Electric Reliability Council, October 1989).

[68] At DOE's request, the Justice Department joined a lawsuit by two local groups opposed to the decommissioning. The challengers allege that the Nuclear Regulatory Commission's (NRC) decision was improper because it failed to assess the environmental impacts of shutting down the plant as required under the National Environmental Policy Act of 1969. The Federal Appeals Court for the D.C. Circuit has rejected the plaintiffs' request for an order staying the NRC's approval of a possession-only license that allows dismantling of the Shoreham plant. *INSIDE ENERGY/with FEDERAL LANDS*, July 22, 1991, p. 10.

[69] *Short-Term Petroleum Fuel Switching*, supra note 16, table FE2.

[70] These include electric generation from such renewable sources as waste, wood, agricultural waste, biomethane, MSW, solar, wind, geothermal, and hydro.

[71] North American Electric Reliability Council, supra note 62.

Expansion of transmission facilities in New England and Canada was recently completed to bring 2,000 MW of power from Hydro-Quebec to the Northeast under long-term contract.[72] The power deliveries that began in 1990 are considered an interruptible supply at present, but are expected to be reclassified as firm capacity in summer 1991. This bulk power purchase further increases regional capacity margins, providing additional flexibility to the region if oil generation is constrained by fuel shortages.[73]

Other Renewable Power Generation—During an oil supply shortfall, the growth in renewable fuels-based capacity is expected to accelerate, based on the mix of fuels specific to a region. For example, solar thermal technology is available commercially and could be deployed to a much greater extent in Western States.[74] Similarly, wind power, which has been concentrated in California, is expected to be deployed commercially within 2 to 3 years in colder climates such as that of the Northeast.[75]

OTA estimates that in a crisis, about 5,000 MW of renewable fuels-based generation—from MSW, biomass, solar, and wind—could be added to displace about 95,000 B/D.[76] Although this would be a significant increase in capacity (a 45-percent increase over 1989), it would not appear to be out of line with some current projections, given the current state of development of renewable technologies. For example, Luz International plans to have 680 MW of hybrid solar thermal capacity in California by 1994, with module size increasing from 80 to 200 MW. The first installed 80 MW unit has started operating, but financial difficulties threaten to delay completion of the remaining capacity additions. Moreover, the United States already has an installed wind turbine capacity of 1,500 MW. Finally, a 10,000 tons per day (TPD) MSW plant, equal to about 30 percent of New York City's daily waste generation, can produce 200 MW, based on an average potential of 2 MW per 100 TPD of MSW throughput. In general, utilities have been more receptive to renewable technologies as the result of their experience with existing units. Several independent power subsidiaries of large utilities are already participants in renewable energy ventures in California and elsewhere.

Coal

Electric utilities could further reduce oil consumption by greater use of coal-fired generation. Three technical options are available:

1. shifting to existing or new coal-fired generation,
2. switching from oil to coal in oil/coal-capable facilities, and
3. converting oil-fired generating plants to burn coal.

Load shifting from oil plants to coal-fired plants has been used within a utility or power pool and through negotiated agreements for sale and transfer of electric power from coal. Expansion of interregional "coal by wire" transfers may be limited by available transmission capacity in eastern utility systems. Even though construction and upgrading of transmission lines has become more controversial and difficult because of environmental and other siting concerns in recent years, new or upgraded lines have been built to take advantage of coal-fired generation. There may be some additional instances where such transfers and needed transmission upgrades may be cost-effective and feasible for backing out oil.

According to DOE, there are about 30,000 MW of dual-fired, coal/oil generating units. Most of these are in the South and Midwest.[77] Probably most of these dual-fuel units are burning coal for economic reasons, and little switching capability remains.

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[72] See discussion of the Phase I and Phase II Hydro-Quebec transmission projects in OTA, *Electric Power Wheeling and Dealing,* supra note 64, pp. 188-189.

[73] OTA, *Electric Power Wheeling and Dealing,* supra note 64, and personal communication to OTA from Paul Shortley, Manager, New England Power Exchange (NEMEX) Operations, Planning and Procedures, Springfield, MA, Nov. 9, 1990.

[74] Dennis Horgan, Luz International, personal communication to Renova Engineering, P.C., OTA contractor, Sept. 19, 1990 and Dan Jaffe and Robert E. Herbster, "SEGS VIII Solar-Power Project: Apply Latest Technology at Solar-Powered Generating Plant," *Power,* April 1990, p. S-19.

[75] Mark T. Hoske, "Vermont De-Icing Demonstration may Allow Northern Wind Farms," *Electric Light and Power,* p. 3, September 1990. David Ward, U.S. Windpower, Inc. personal communication, to Renova Engineering, P.C., OTA contractor, Sept. 26, 1990.

[76] We have assumed a deployment of 5,000 MW in 5 years—a mid-range between the DOE estimate and that by RCG/Hagler. Assuming this capacity replaces an equivalent oil-based capacity operating at a 50 percent capacity factor with an average heat rate of 10,000 Btu/kWh, to yield an estimated oil replacement potential of 95,000 B/D.

[77] Jones, supra note 58.

Many utilities converted to coal in response to the energy crises of the 1970s. The easiest conversions involved plants originally designed to burn coal and later converted to burn oil. It is likely that most such oil units have already been reconverted for coal, while the rest remain oil units because of cost, emissions problems, or lack of space for auxiliary coal transport, storage, handling, and waste disposal facilities.

Other oil-fired boilers suitable for conversion to coal are those that are technically similar to coal-designed boilers. OTA's 1984 analyses found that 114 oil-burning utility boilers in Federal regions 1 through 4 and 9 might be suitable for converting to coal or CSF.[78] Finally, the remaining oil boilers are so dissimilar to coal boilers that it would be neither technically nor economically practical to convert them to coal.

Converting oil-only units to burn CSF usually entails derating these units. The extent of derating depends on plant-specific and CSF-specific factors.[79] On average, the loss in capacity would be about 35 percent. If all 26,500-MW of oil-only capacity in Regions 1, 2, 3, and 4 (see table 3-12) were converted to CSF, capacity could be reduced by about 9,500 MW. Such coal conversion would require permit approvals and significant alterations to the generating plant. However, incorporating capacity and efficiency improvement measures as part of these conversions would minimize any potential derating of the units.

Building new coal-fired capacity to displace oil-fired units is also an option. Commercially available options include conventional coal-fired steam turbines, fluidized-bed combustion systems (now being adapted for use at utility scales), and integrated gasification combined-cycle (IGCC) systems (only recently available commercially for utility applications). According to NERC, 14,400 MW of additional utility and NUG coal-based generating capacity is planned to come on line between 1991 and 1999.[80]

Although the technology is relatively new, IGCC or coal gasification combined cycle (CGCC) plants have been successfully demonstrated at the Coolwater plant in California and at Dow Chemical's Plaquemine, Louisiana, plant, and CGCC technology is now being offered for commercial deployment.[81] Several utilities plan to install CGCC plants.[82] The CGCC technology also has attracted independent power producers. For example, assuming that public opposition is overcome, Texaco plans to bring on line in 1995 a 440-MW plant in the Northeast. Destec Energy, a Dow Chemical subsidiary, is offering a 200-MW module and has announced a 230 MW repowering project in Indiana scheduled to go commercial in 1995.[83]

The oil-replacement potential for the above coal-based options will depend on the final decisions made by industry participants and may well rest on considerations other than the desire to reduce oil use. It is nevertheless technically feasible to use coal-fired generation to eliminate virtually all of utilities' heavy oil consumption. If natural gas, nuclear, and renewable fuels options replaced about 240,000 B/D, coal could, at a minimum, replace 85 percent of the remaining oil, or about 360,000 B/D. (This assumed use of coal-based options is tied to uncertainties over natural gas availability and the acceptability of coal burning to local communities. Greater availability of natural gas could reduce the amount of coal used to replace oil.)

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[78] OTA, *The Oil Replacement Capability*, supra note 1, pp. 60-62 and 79-81.

[79] H.R. Beal et al., "Coal-Water Fuel Retrofit Evaluations," paper presented at Coal—Targets of Opportunity Workshop, U.S. Department of Energy, July 12-13, 1988, Washington, DC.

[80] Jean-Louis Poirier, "How NUG Capacity Is Growing," *Electric Light and Power*, p. 22, February 1990. Douglas J. Smith, "Natural Gas Will Fuel Future Non-Utility Plants," *Power Engineering*, p. 13, September 1989.

[81] "Gasifier Demo Heralds New Era for Gas Turbines," *Power*, page S-24, October 1989. Jason Makansi, "Coal Gasification Breaks Out of Synfuels/Clean Coal Pack," *Power*, p. 56, April 1990. M. Rao Goineni et al., "Advanced Energy Technologies at Combustion Engineering, Inc.," paper presented at "Coal—Targets of Opportunity Workshop," U.S. Department of Energy, July 12-13, 1988, Washington, DC. Mark Roll, Destec Energy, personal communication to Renova Engineering, P.C., OTA contractor, Oct. 12, 1990 and information submitted by Destec. Robert Smock, "Repowering Old Plants Gains Favor," *Power Engineering*, p. 25, May 1990.

[82] Robert Smock, "New Gas Turbines Show High Efficiency, Low NOx Emission," *Power Engineering*, p. 43, August 1990.

[83] Marie Leone, "New Powerplant Projects," *Power*, December 1990, p. 15.

Demand Management

In addition to conventional supply side resources, many utilities now look to improved efficiency and conservation efforts on the demand side as a cost-effective means to provide needed capacity. Demand management broadly refers to activities undertaken by a utility or a customer to influence electricity use. Among the variety of activities used for demand management are: utility rate programs (time of use or time of day, interruptible rates, real-time pricing, waiver of demand charge under certain conditions, and other financial incentives, such as rebates, for consumers who invest in energy efficient equipment.

The use of demand management programs by utilities for energy efficiency and peak load reduction is widespread and the benefits are obvious. For example, the Northeast Power Coordinating Council, which includes New England and New York, plans demand management programs totaling 3,850 MW between 1990 and 2000. During a crisis, oil dependent utilities could intensify demand management programs. A reasonable assumption is that such expanded efforts could reduce peak demand by about 4,000 MW (3 percent of peak for oil dependent regions). Thus, they could displace about 15,000 B/D of oil based on an equivalent oil-based capacity operating at a 10 percent capacity factor and an average heat rate of 10,000 Btu/per kilowatt hour (kWh).[84]

Deployment Constraints and Schedule

Achieving this level of oil replacement does, however, present some uncertainties. Areas of potential constraints include natural gas supplies, turbine manufacturing capability, environmental permitting, effects of electricity demand growth, and capacity margins.

Natural Gas Availability

Several new pipeline projects are being developed to supply domestic and Canadian natural gas to the Northeast and California and should make natural gas more available to all sectors. These projects are in various stages of development and approval[85] and, once approved, could displace more utility oil use directly or through NUGs. The Iroquois pipeline approved by the Federal Energy Regulatory Commission (FERC) in fall 1990 will bring 576 million cubic feet of natural gas from Canada to New York and New England—the equivalent of 100,000 B/D of crude oil. Some portion of this gas will be committed under firm deliveries to electric utilities and independent power producers. Natural gas availability issues are further discussed later in this chapter.

Manufacturing of Turbines

In 1989, the total installed summer generating capacity of the United States was about 673,000 MW. By 1995, that capacity is projected to grow by about 40,000 MW. Of this new capacity, about 16,000 MW is not yet under construction, and of this amount about 10,000 MW will be based on short lead-time generators, such as combustion turbines (also known as gas turbines), jet engines, and internal combustion (diesel) engines. Some analysts have questioned whether the combustion turbine manufacturers can meet this normal growth in new orders, since most of the capacity will be installed after 1992. In our 1984 report we concluded that manufacturing capability should not be a problem, even with an acceleration in orders. We still believe that this conclusion is valid and note that other analysts have reached similar results.[86] The annual production capacity of major U.S. combustion turbine manufacturers in 1990 was 14,000 MW, more than adequate to meet U.S. and foreign demand, and manufacturers note plans to expand capacity to meet expected new demand in the 1990s. Annual planned additions of combustion turbines by domestic utilitites, according to NERC data, were up to 5,000 MW per year. Lead-time from purchase to commercial operation is 18 to 24 months. It would appear that an increase of 1,000 to 2,000 MW in orders for accelerated oil replacement capacity could be met. We have therefore assumed that this would not delay the deployment of oil replacement technologies in the electric utility sector.

Environmental Permitting Process

All of the oil replacement technologies can attain compliance with environmental regulations. However, a relatively smooth permitting process would be necessary so that the various conversion and replacement projects could obtain the required environmental permits in 12 to 18 months. This appears to be feasible. A survey of combustion turbine installations found that permitting is achieved in most cases in under 18 months.[87]

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[84] Renova Engineering, P.C., supra note 4, at p. 23.

[85] American Gas Association, "New Pipeline Construction Projects-Status Report," Issue Brief 1990-95, Apr. 13, 1990.

[86] John R. Riley, Gregory L. Gould, and Richard A. Klover, "Can Manufacturing Capacity Keep Up With New Orders for CTs?" *Power Engineering*, vol. 94, No. 4, April 1990, pp. 45-47.

Shoreham Nuclear Plant

The State of New York is exploring the feasibility of converting the mothballed Shoreham plant to natural gas. Such a conversion will have to overcome natural gas supply, permitting, and financing hurdles. On the other hand, a nuclear restart might entail less financial difficulties but would have to overcome public, State, and local government opposition. We have not assumed the availability of Shoreham capacity.

Capacity Margins and Demand Growth

Some analysts have made dire projections of an impending crisis in supplying generating capacity if high rates of electricity demand-growth reappear and utilities do not accelerate construction plans. Others have voiced concern that oil replacement options might worsen any possible capacity shortfall.

Of the various options, only CSF firing in oil-only units would reduce generating capacity through derating, thus narrowing capacity margins. But capacity losses through plant derating are not expected to be a significant deterrent to fuel switching. The loss could be made up by other capacity additions, in particular, existing nuclear plants, renewable fuels, coal-based plants, and CGCC or by repowering some of the older oil and non-oil units. According to one study, repowering of old oil-steam plants to combined cycle gas turbines could add 2 MW of gas generation for every 1 MW of oil generation replaced.[88]

We have not made any detailed examination of the impacts of differences in electricity demand growth on our oil replacement estimates. We do note that capacity margin estimates include some consideration of demand growth. Where judgments are based on availability of sufficient capacity margins to displace oil, some demand growth is implicit.

Estimated Oil Replacement Technology Deployment

Table 3-13 summarizes the breakdown of the 0.6 MMB/D of oil that could be replaced in electric utilities by the various options assessed above. Assuming that the possible constraints are indeed overcome, the actual replacement of oil over the 5-year period could take place as follows:

1. Switching to natural gas immediately to replace 85,000 B/D of oil.
2. Operation of the completed nuclear plants could replace 44,000 B/D. The schedule would depend on debugging delays for Limerick Unit 2 and Seabrook Unit 1. We have assumed that the nuclear option displaces oil starting in 1993.
3. Several renewable fuel-based NUGs are probably under construction. There also exists a diverse mix of technology options for any new capacity that is in planning. Hence, renewable fuels might replace 95,000 B/D uniformly over the 5-year period.
4. The coal-based options are a mixed bag. It is assumed that coal-based plants in the design and construction phases will replace about 90,000 B/D over the first 3 years, while the remaining 75 percent, or 270,000 B/D, are replaced uniformly over the last 2 years. One reason for this delay is that the suppliers of CSF technology have shelved their developmental efforts during the last 3 to 4 years because of low oil prices and, therefore, a 12 to 18-month mobilization period will be required.

The estimated deployment schedule over 5 years is shown in table 3-14. Natural gas fuel switching, coal, renewables, and demand management are available to displace oil in the first 2 years. In years 3 to 5, nuclear capacity, and larger coal-fired units begin to come on line.

Estimated investment costs for the various oil replacement options are shown in table 3-15. Estimated investment costs for each B/D replaced range from $0 for use of available capacity from existing gas and nuclear units to as much as $420,000 for a MSW plant operating at a 50 percent capacity factor. Actual costs could vary significantly from these depending on the characteristics of local utilities and loads.

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[87] Ibid.

[88] Smock, supra note 81, pp. 25-27.

Table 3-14—Deployment Schedule for Oil Replacement Technologies in the Electric Utility Sector (oil replacement potential—thousand barrels per day)

		Fuel switching option			Demand	
Year	Gas[a]	Nuclear[b]	Renewables[c]	Coal[d]	management	Total[c]
1991	85	0	19	30	3	137
1992	85	0	38	60	6	189
1993	85	15	57	90	9	256
1994	85	29	76	225	12	427
1995	85	44	95	360	15	599

[a] Assumes utilities could switch to natural gas in the first year.

[b] Uniform displacement after 1992. Excludes Shoreham Unit.

[c] Assumes a uniform oil displacement over 5 years.

[d] Assumes that coal-based NUG plants in the design and construction phase replace 25% of the oil over the first 3 years with the remaining 75% replaced by all coal-based options over the last 2 years.

SOURCE: Office of Technology Assessment, 1991, based on Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

THE INDUSTRIAL SECTOR

The industrial sector includes both *manufacturing* enterprises (i.e., businesses that convert raw materials into intermediate or finished products) and *nonmanufacturing* activities, such as agriculture, forestry, construction, mining, and oil and gas production. This diversity is reflected in the variety of oil products, and end-use applications in the industrial sector. Although oil use is widespread in this sector, much of the oil consumption is concentrated in certain industries, applications, and regions. (See figure 3-6.)

Oil use in the industrial sector in 1989 totaled 4.26 MMB/D or about one-quarter of total U.S. oil consumption.[89] Petroleum accounted for about 36 percent of industrial sector energy use in 1989, down from 38 percent in 1983.[90] Petroleum products used in industrial applications consisted of 820,000 B/D of distillate and residual fuel oil, and 3.4 MMB/D of nonfuel oil products, mostly feedstocks.[91] By 1989, the industrial sector was using 1 MMB/D less oil, and less energy overall, than it was in 1979. Table 3-16 shows industrial oil use in 1979, 1983, and 1989.

The industrial sector is characterized by diverse, complex, and rapidly changing technology, which complicates estimates of future consumption and potential oil savings. The sector has a variety of effective options for adjusting to oil supply or price disruptions, including fuel switching, substitution of non-oil based products, process changes, and improvements in management and control technologies. OTA estimates that potential oil savings in the industrial sector during a prolonged oil import disruption could total about 800,000 after 5 years.

Patterns of Industrial Oil Use

The major energy and oil needs of the manufacturing sector are for heat, power, and feedstocks (see figure 3-7 and table 3-17). The manufacturing sector consumed 275,000 B/D of distillate and residual fuel oil in 1989, almost exclusively for steam generation in boilers, process heat, and cogeneration of electric power. Although these applications are but a small portion of total industrial oil use, they represent major opportunities for displacing oil use in the near-term. Nonfuel oil use in manufacturing was 979,000 B/D in 1989.

The nonmanufacturing sector consumed about 3 MMB/D of petroleum products in 1989 (see table 3-17). Distillates, primarily diesel fuel, accounted for about 493,000 B/D, and residual fuel oil consumption

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[89] *Annual Energy Review 1989*, supra note 6, table 61.

[90] Among the major factors that account for the decline in oil use and energy demand in the industrial sector in the past two decades are increased efficiency, greater use of electricity, and waste and byproduct fuels, and structural changes in the composition of the industrial sector. Precise estimates on the relative contributions of these factors to oil savings are not easily derived. However, OTA's own review found that for the economy as a whole, increased efficiency was responsible for two thirds of the decline in energy consumption and structural change for the remaining third. Changes in the manufacturing sector accounted for two fifths of these savings. U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy*, Background Paper, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990), p. 4.

[91] *Annual Energy Review 1989*, supra note 6, table 62.

Table 3-15—Estimated Investment Costs for Oil Replacement Technologies in the Electric Utility Sector
(approximate investment cost in thousand 1990 dollars per barrel per day of oil replaced)

Option	$000 per B/D replaced[a]		Percent capacity factor	Remarks
	Minimum	Maximum		
Natural gas	0	34	50	Maximum cost based on replacing the capacity with a 240-MW combined cycle plant at $650/kW.[b]
Nuclear	0	13	50	Maximum cost assumed at $250/kW to debug plants that went into commercial operation in 1990.[b]
Renewable fuels				
Solar	131	153	36	80-MW solar thermal plant with gas firing at supplemental $1,800-$2,100/kW.[c]
Wind energy	63	125	21	Wind energy farm at $500-$1,000/kW.[d]
Wood	79	95	50	20-MW wood-fired plant at $1,500-$1,800/kW.[e]
Municipal solid waste	263	420	50	20-MW MSW-fired plant at $5,000-$8,000/kW.[e]
Coal				
Coal/CSF	4	16	50	Conversion of coal capable units assumed at at $80-$300/kW.[f]
CSF	4	29	50	Conversion of oil-only capable units at $80-$550/kW of derated capacity.[f]
Coal	68	89	50	150-MW plant using pulverized or circulating fluidized bed coal at $1,300-$1,700/kW.[b]
CGCC	63	74	50	200- to 360-MW CGCC plant at $1,400-$1,200/kW.[g]
Demand management	92	105	10	Equivalent to an 80-MW combustion turbine at $350-$400/kW.[b]

[a] Assumed that the option replaces an equivalent oil-based capacity operating at 10,000 Btu/kWh and the specified capacity factor.

[b] Robert W. Smock, "Need Seen for New Utility Capacity in '90," *Power Engineering*, April 1990, p. 29.

[c] Dennis Horgan, Luz International, personal communication to Renova Engineering, P.C., Sept. 19, 1990, and information made available by Luz International.

[d] David Ward, U.S. Windpower, Inc. personal communication to Renova Engineering, P.C., Sept. 26, 1990.

[e] In-house Renova Engineering files.

[f] H.R. Beal et al. "Coal-Water Fuel Retrofit Evaluations," paper presented at Coal —Targets of Opportunity Workshop, DOE, July 12-13, 1988, Washington, DC mentions 1985 conversion cost of $60-$420/kW of derated capacity for noncoal-capable units, depending on the CSF quality and unit constraints. This cost was increased by 30 percent to get 1990 dollars. For coal capable units, it was assumed that the cost would vary between $80-$300/kW depending on the CSF quality and the extent of flue gas clean-up system.

[g] Mark Roll, Destec Energy, personal communication to Renova Engineering, P.C., Oct. 12, 1990. Eric Jeffs, "Coal Fired IGCC Plants are at the Threshold of Commercial Operation," *Gas Turbine World*, March-April 1988. U.S. Congress, Office of Technology Assessment, *New Electric Power Technologies: Problems and Prospects for the 1990s*, OTA-E-246 (Washington, DC: U.S. Government Printing Office, July 1985).

SOURCE: Office of Technology Assessment ,1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

was about 52,000 B/D. Farm use includes fuel for tractors, irrigation pumps, agricultural machinery, crop drying, space heating, and cooking. Off-highway distillates are used to power construction equipment (cranes, compressors, and generators) and for other applications. The remaining nonmanufacturing uses include fuels for oil drilling and production equipment, remote electric generators, and nondiesel construction equipment, and other miscellaneous activities.[92] There are only limited short-to mid-term

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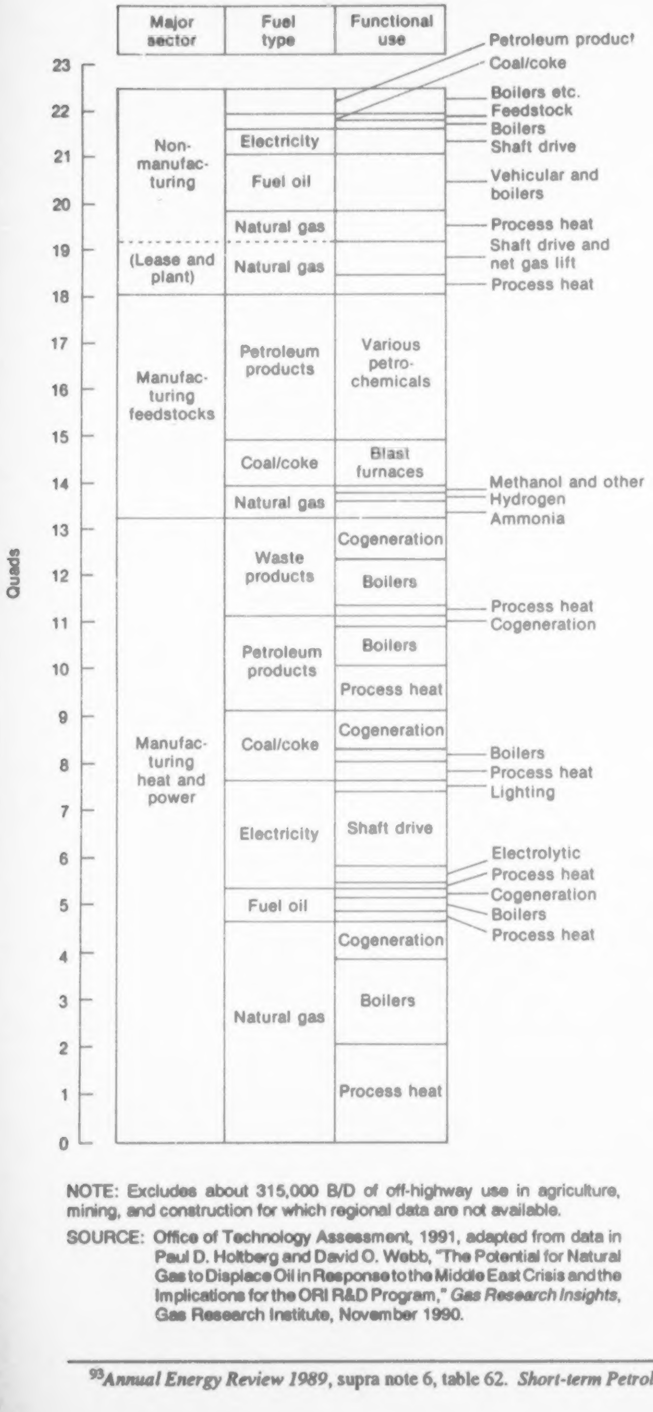
[92] OTA estimates based on data from *Annual Energy Review 1989,* supra note 6, and product shares reported in *Short-Term Petroleum Fuel Switching,* supra note16, pp. 12-14, and tables 5 and 8.

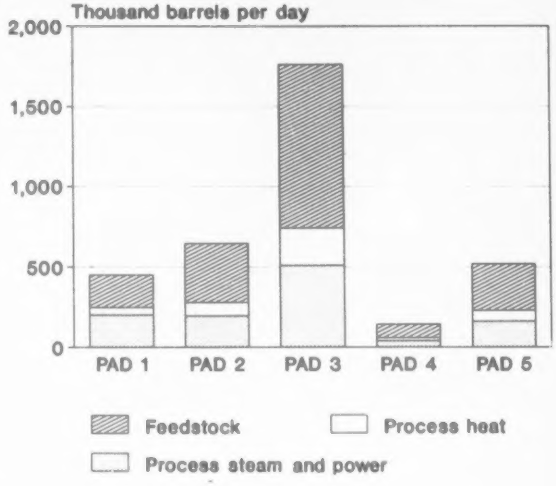
Figure 3-6—Oil Use in the Industrial Sector by Region and Application


Major sector
Fuel type
Functional use
Quads
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Non-manufacturing
(Lease and plant)
Manufacturing feedstocks
Manufacturing heat and power
Electricity
Fuel oil
Natural gas
Natural gas
Petroleum products
Coal/coke
Natural gas
Waste products
Petroleum products
Coal/coke
Electricity
Fuel oil
Natural gas
Various petro-chemicals
Blast furnaces
Cogeneration
Boilers
Boilers
Process heat
Cogeneration
Shaft drive
Cogeneration
Boilers
Process heat
Petroleum product
Coal/coke
Boilers etc.
Feedstock
Boilers
Shaft drive
Vehicular and boilers
Process heat
Shaft drive and net gas lift
Process heat
Methanol and other
Hydrogen
Ammonia
Process heat
Cogeneration
Boilers
Process heat
Lighting
Electrolytic
Process heat
Cogeneration
Boilers
Process heat

NOTE: Excludes about 315,000 B/D of off-highway use in agriculture, mining, and construction for which regional data are not available.

SOURCE: Office of Technology Assessment, 1991, adapted from data in Paul D. Holtberg and David O. Webb, "The Potential for Natural Gas to Displace Oil in Response to the Middle East Crisis and the Implications for the ORI R&D Program," *Gas Research Insights*, Gas Research Institute, November 1990.

Figure 3-7—Profile of Energy Use in the Industrial Sector, 1985



SOURCE: Office of Technology Assessment, 1991, from data in Gas Research Institute, "Industrial Natural Gas Markets: Facts, Falacies and Forecasts," March 1989.

options for replacing most of these nonmanufacturing oil uses.

In 1989 over 2.46 MMB/D of nonfuel oil products were consumed in nonmanufacturing activities. The products in this category include LPG, petrochemical feedstocks, still gas (a byproduct of the petroleum refining process used primarily as a captive fuel and not sold commercially), petroleum coke (another refinery byproduct), asphalt, road oil, motor gasoline, kerosene, lubricants, waxes, and other petroleum products (table 3-16).[93] This category, often referred to simply as "feedstocks," accounts for over 11 percent of total U.S. petroleum consumption—an amount second only to transportation uses. As in our 1984 report, we found that there continues to only limited technical potential for replacement of nonfuel oil products in the short term.

LPG accounts for the largest quantity of nonfuel oil products in the industrial sector. About 97 percent of industrial LPG consumption is for nonmanufacturing applications, such as crop drying or feedstocks in the petrochemical industry.

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[93] *Annual Energy Review 1989*, supra note 6, table 62. *Short-term Petroleum Fuel Switching*, supra note 16, table 8.

Table 3-16—Industrial Consumption of Oil Products, 1979, 1983, and 1989
(million barrels per day)

Oil product	1979	1983	1989
Fuel oils	1.55	0.93	0.82
Distillate	0.83	0.61	0.57
Residual	0.72	0.32	0.25
Feedstocks & other non-fuel oil products	3.80	3.02	3.44
Asphalt and road oil	0.48	0.37	0.45
Liquefied petroleum gases	1.27	1.17	1.25
Lubricants	0.09	0.08	0.08
Motor gasoline	0.08	0.06	0.10
Kerosene	0.08	0.07	0.02
Other products	1.79	1.27	1.54
Total	5.34	3.93	4.26

SOURCE: Office of Technology Assessment, 1991, based on data from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990); *Annual Energy Review 1984*, DOE/EIA-0384(89), April 1985; and *Annual Energy Review 1985*, DOE/EIA-0384(85), May 1986.

Also included among nonfuel oil products are waste fuels and byproducts such as still gas and petroleum coke used in the petroleum refinery and petrochemical industries in preference to purchased fuels such as natural gas. This pattern of internal-captive fuel use means that operators will tend not to replace these oil products even when technically feasible to do so unless there are significant cost advantages to switching to other fuels. Moreover, some of these byproducts could not be easily diverted to other applications and might have to be disposed of in some other manner if not used as waste fuels.

Oil Replacement Potential

OTA estimates that the industrial sector could technically displace about 800,000 B/D of petroleum products, or about 20 percent of its consumption, as shown in table 3-18. The oil replacement options in the industrial sector include credit for reducing refinery throughput (360,000 B/D) and the savings that would result from switching to natural gas (297,000 B/D) and other fuels (50,000 B/D) for process heat, steam, and power generation, and from intensifying the adoption of more energy-efficient process changes (100,000 B/D) in manufacturing.

In our 1984 report, we estimated that the industrial sector could save 1 MMB/D, or 25 percent of its energy use through increased efficiency and process changes (including credit for reduced refinery throughput of 220,000 B/D).

Our present analysis suggests that U.S. flexibility in replacing oil in the industrial sector has declined by over 340,000 B/D since 1984 (exclusive of net savings from reduced refinery throughput). This decline partly reflects a greater reliance on natural gas, electricity, and byproduct fuels and already achieved efficiencies in oil use.

Reduced Refinery Throughput

OTA estimates that about 360,000 B/D of oil could be saved through reduced internal fuel consumption in the next 5 years. Refineries use about 580,000 Btu, or about 0.1 barrel of fuel per barrel of crude input as fuel for various internal processes such as distillation and cracking.[94] A reduction in crude oil processed through U.S. refineries yields a net savings in refinery oil consumption of about 10 percent of the lost throughput. In 1989, U.S. refineries imported about 5.8 MMB/D of crude oil and 2.2 MMB/D of other petroleum products.[95] Based on this import mix, we have assumed that the 5 MMB/D of total shortfall in imports consists of about 3.6 MMB/D of crude oil and 1.4 MMB/D of petroleum products.

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[94] OTA, *The Oil Replacement Capability*, supra note 1, p. 112 and Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference*, vol. 2, Part 1 of 3, End Use Technology, ORNL 6541/V2/P1 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1989), p. 74.

[95] *Annual Energy Review 1989*, supra note 6.

Table 3-17—Industrial Oil Use: Consumption in the Manufacturing and Nonmanufacturing Subsectors, 1989
(thousand barrels per day)

Product	Manufacturing use[a]	Nonmanufacturing use: Farm and off-highway diesel use[a]	Nonmanufacturing use: Other nonmanufacturing[a]	Total nonmanufacturing[b]	Total manufacturing and nonmanufacturing
Fuel oil					
Distillate	77	310	183	493	570
Residual	198	0	52	52	250
Subtotal	275	310	235	545	820
Non-fuel oil					
LPG	42	c	c	1,208	1,250
Other	937	c	c	1,253	2,190
Subtotal	979	c	c	2,461	3,440
Total	1,254	c	c	3,006	4,260

[a] Consumption prorated from U.S. Department of Energy, Energy Information Administration, *Estimates of Short-Term Petroleum Fuel Switching Capaility*, DOE/EIA-0526 (Washington, DC: U.S. Government Printing Office, May 1989).
[b] Total consumption as reported in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 62.
[c] The breakdown of non-fuel oil use in nonmanufacturing applications is not reported separately. The non-fuel oil amount is reported as a subtotal for nonmanufacturing use.
[d] Includes asphalt and road oil, still gas, petroleum feedstocks, petroleum coke, and other petroleum products.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991 .

Table 3-18—Estimated Oil Replacement Potential in the Industrial Sector (thousand barrels per day)

Oil replacement option	Manufacturing: Fuel oil[a]	Manufacturing: Non-fuel oil[b]	Manufacturing: Subtotal	Nonmanufacturing: Fuel oil[a]	Nonmanufacturing: Non-fuel oil[b]	Nonmanufacturing: Subtotal	Total
Reduce refinery throughput					360	360	360
Switch to natural gas	177	65	242	55		55	297
Convert to other fuels	c		c	c		c	50
Process changes	d		d		d	d	100
						Total	807

[a] Consists of distillate and residual oil.
[b] Consists of LPG and other non-fuel oil products.
[c] Less than 50,000 B/D in all uses.
[d] Less than 100,000 B/D in all uses.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

In the significant oil supply shortfall assumed in this study, refinery throughput would be reduced by 3.6 MMB/D, thus cutting internal fuel consumption by about 0.36 MMB/D. This would effectively reduce the imported crude oil shortfall from 3.6 MMB/D to 3.24 MMB/D, an amount offset somewhat by any increase in refinery runs from increased domestic production or crude oil stock drawdown from the SPR or private stocks.

Conversion to Natural Gas

Natural gas is already a major fuel and feedstock in the industrial sector, representing about 37 percent of industrial energy use. Switching to natural gas could displace 232,000 B/D of fuel oil. Natural gas could displace oil in dual-fuel capable facilities and as a feedstock for some uses. Existing oil-only facilities might be converted for natural gas, provided that gas supplies are available.

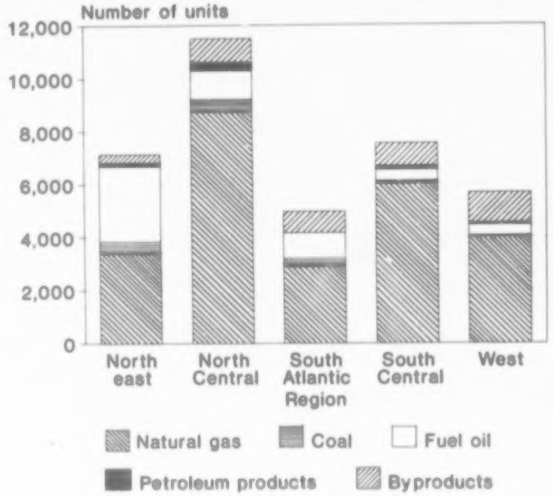
DOE lacks the detailed information on fuel switching capability in the industrial sector comparable to that for electric utilities. Their estimates are based on extrapolations from surveys of a carefully selected pool of industrial users in the five most energy intensive manufacturing industries. Estimates of potential savings are based on assumptions that certain comparable savings could be achieved across the sector.

Fuel Oil Replacement—In the industrial sector, switching from fuel oil to natural gas could displace 177,000 B/D of oil. Price volatility and gas supply curtailments have spurred U.S. industry to improve its flexibility in fuel choices for industrial facilities over the past 2 decades. Many dual-fuel capable industrial facilities are already using gas rather than oil because of the lower relative price of natural gas. The switching that has already occurred, however, limits the potential for further switching from oil to gas.

The major target for fuel switching in the industrial sector is oil used for industrial boilers. Some 36,820 boilers are used in the manufacturing sector.[96] (See figure 3-8.) Natural gas is the dominant boiler fuel in 68 percent of all industrial boilers. Oil-fired boilers include 5,845 units that burn fuel oil (mostly residual) and 575 that burn petroleum products (mostly still gas). Oil-fired boilers make up a large share of boiler units and capacity in the Northeast and South Central regions as shown in figure 3-8.

About half of all industrial boilers now have dual-fuel or backup fuel capability. About 53 percent of fuel oil-fired boilers and almost all of the petroleum product boilers have dual-fuel capability.[97] Among some dual-fuel boilers, the backup fuel is distillate or residual fuel oil. There is no oil replacement capability for these boilers, but perhaps some flexibility in fuel choice could ease demands for fuels in shorter supply in a crisis.

Figure 3-8—Distribution of Industrial Boilers by Region and Primary Fuel Type



SOURCE: Office of Technology Assessment, 1991, from data in Gas Research Institute, "Industrial Natural Gas Markets: Facts, Falacies and Forecasts," March 1989.

DOE estimates that the manufacturing sector's large built-in flexibility for switching residual and distillate fuel oil to other fuels, primarily natural gas, could reduce fuel oil consumption in less than 30 days by about 79,000 B/D of fuel oil, consisting of 7,000 B/D of distillate oil and 72,000 B/D of residual fuel oil.

The almost 2,700 oil boilers that do not have fuel switching capability may be attractive candidates for replacement with gas-fired units. Assuming a 20-year equipment life, typically 25 percent of the boilers would be replaced over a 5-year period under normal conditions.[98] (About 67 percent of the oil-fired boilers were installed before 1970, and 44 percent were installed before 1960).[99] This normal replacement rate, assumed by DOE, could be doubled in a crisis. Doing so would displace an additional 50 percent of the remaining 196,000 B/D, or about 98,000 B/D of fuel oil, consisting of 35,000 B/D of distillate oil and 63,000 B/D of residual fuel oil.

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[96] Gas Research Institute, *Industrial Gas Markets: Facts Falacies and Forecasts*, March 1989.

[97] Ibid.

[98] U.S. Department of Energy, *Manufacturing Energy Consumption Survey: Fuel Switching 1985*, DOE/EIA-0515(85) (Washington, DC: U.S. Government Printing Office, May 1989), figure 1, p. 18.

[99] Gas Research Institute, supra note 96.

Information on the fuel oil-switching capability in the nonmanufacturing sector is sparse to nonexistent. However, patterns of oil product use in these sectors suggest that farm and off-highway diesel usages offer a very limited potential. In its analysis DOE assumed that oil companies and other miscellaneous users in the nonmanufacturing sector have a switching potential comparable to that for the manufacturing sector. As a result, DOE has estimated the gas conversion potential in the nonmanufacturing sector to be about 10 percent, or about 55,000 B/D.[100] In the absence of more detailed information on manufacturing fuel-switching capability, we have adopted the DOE estimates.

Nonfuel Oil Replacement—The near-term potential for replacing oil directly in nonfuel oil uses is limited to the manufacturing sector where natural gas could substitute for some LPG and marketable petroleum coke. Assuming a switching capability comparable to that for coal and coal coke used as fuel in the manufacturing sector, DOE has estimated the potential to be about 6 to 7 percent of the 979,000 B/D of nonfuel oil products consumed in the manufacturing sector, or about 65,000 B/D of nonfuel oil petroleum products.[101]

In summary, natural gas could replace about 297,000 B/D of petroleum products, comprising 232,000 B/D of fuel oil (177,000 B/D in the manufacturing sector and 55,000 B/D in the nonmanufacturing sector), and 65,000 B/D of nonfuel oil products in the manufacturing sector.

Conversion to Other Fuels

About 10 percent or 50,000 B/D of the remaining consumption of distillates and residual fuel oil could be displaced by some combination of coal, electrification, and renewable technologies.

Coal—Some manufacturing applications that use residual fuel oil might be suitable for coal-based technologies such as CSF, micronized coal, and coal gasification. Assuming that 50 percent of the oil-only capable units are replaced by natural gas-fired units over 5 years, coal-based technologies could, in principle, displace the remaining 50 percent, or about 63,000 B/D of residual fuel oil. The CSF and coal gasification technologies are commercially available, as discussed in the previous section on electric utilities. Some ongoing experiments and demonstrations involving the use of coal in utility boilers might be applicable to industrial uses. Micronized coal technology has also been used successfully in packaged oil-fired boilers.[102] It is not known how suitable some of these uses may actually be for conversion to coal burning from a size, applications, or environmental permitting perspective. However, based on earlier reviews, it seems technically feasible to convert at least some of these facilities to coal. There are already several examples of coal gasification-driven industrial applications in operation or planning.[103]

Renewables—Small, biomass-fired, electric generating units could be deployed to displace distillate oil used in some of the agricultural applications such as space heating, irrigation pumps, and farm machinery. Units in the range of 1.5 to 5 MW are offered commercially.[104] These would seem most appropriate to larger operations, however. Units fired by agricultural and wood wastes are increasingly used in the timber and food processing sectors. Small, mobile biomass gasifiers could be deployed in rural areas.[105]

In our 1984 report we estimated that contributions from solar photovoltaic (PV) systems and wind turbines would be negligible. Experience since then has indicated that they can be appropriate alternative technologies for certain remote applications. Wind turbines and PV units could be deployed to generate electricity and displace some of the distillate oil used in nonmanufacturing applications. Wind turbine technology is commercially available, as discussed earlier under electric utility technologies. Solar PV systems for remote applications have also been used. They can be cost-effective when compared with tie-ins to central generation. In 1988 about 9,700 kilowatts (kW) (peak) of PV modules were shipped, of which 2,200 kW were for water pumping and industrial or commercial applications.[106]

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[100] *Short-Term Petroleum Fuel Switching*, supra note 16, at p. 18.

[101] Ibid., tables 5 and 7.

[102] Ibid., table 8.

[103] See for example, Dow's plant in Louisiana, under the utility sector earlier in this chapter.

[104] "Biomass-fired Projects Promoted by Cost of Oil," *Engineering News Record*, Sept. 25, 1990, page 25.

[105] OTA, *The Oil Replacement Capability*, supra note 1.

Electricity could be used in some manufacturing and nonmanufacturing applications to substitute for fuel oil and distillates in limited applications, but the amount saved is probably small.

Efficiency Gains and Process Changes

In the past 20 years, the industrial sector has grown less energy intensive (and less oil intensive), reflecting improved efficiencies in manufacturing and processing facilities, especially in process control equipment, electrification, industrial cogeneration, and use of waste heat. This improvement also partly reflects a structural shift in the industrial sector toward goods that require less energy to produce per dollar of final product, and this trend is expected to offer continued savings.[107]

Among the major energy-intensive applications in the industrial sector are thermal processes—heat, distillation, separation, and drying. Several options are available to improve efficiencies in these processes and to replace or reduce oil use. For example, the industry could use alternate non-oil-based feedstocks in certain applications. Heat pump and membrane technologies could cut the demand in chemical and petrochemical plants for heat required in distillation columns. Finally, both industry and consumers could intensify waste minimization and reduction programs.

Use of Heat Pumps in Distillation—Distillation is the most widely practiced energy-intensive/thermal method of separating the components of chemical mixtures in the chemical, petroleum, and gas liquids industries.[108] Almost 30 to 60 percent of the energy demand in chemical and petrochemical plants is for heat required in distillation columns. This energy consumption can be reduced by using heat pumps having payback periods of 1 to 2 years. For example, a propylene plant with a conventional distillation column for propane-propylene splitting uses 2.4 lb of steam per pound of product. This consumption can be replaced by electricity by using a heat pump, saving 600 to 700 B/D in a small 120,000 tons/yr propylene plant. Similarly, a typical 250,000 tons/yr styrene plant could save about 400 to 500 B/D of oil.[109]

In 1990, propylene and styrene plants are estimated to produce about 21 and 8 billion pounds, respectively.[110] More detailed analysis would be necessary to verify the actual industrywide potential of heat pumps in these plants because some plants use waste heat or natural gas, some already have heat pumps, and retrofitting plants for heat pumps would increase the consumption of electricity. Also, many petrochemical plants that already use waste products as a source of heat or electricity may not see a net savings from the use of heat pumps.

Use of Membrane Technology—Membrane technology provides a mechanical means for separating individual chemicals from mixtures by exploiting the differential rates at which various components permeate membrane structures because of their molecule sizes.[111] The traditional applications of membrane technology include gas separation and water desalination plants. Other commercial applications are air drying and dehydration of organic solvents. The dehydration applications use pervaporation membranes in which the permeate is removed as vapor from the downstream side. DOE has identified pervaporation as a top research priority. If a sufficient quantity of selective pervaporation membranes could be made available, these membranes could replace oil products used to provide process heat for distillation.[112]

Waste Minimization—Each year U.S. industry generates 300 million tons/yr of liquid and solid hazardous wastes. It also generates millions of tons of waste gases, which contain about $500 million worth of chemicals. Those nonhazardous industrial solid wastes and wastewater classified as solid waste by the Environmental Protection Agency (EPA), are estimated to be about 613 million tons/yr.[113]

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[106] *Annual Energy Review 1989*, supra note 6, table 103.

[107] *Energy Use in the U.S. Economy*, supra note 90.

[108] ORNL, supra note 94, at p. 70.

[109] Albert Meili, "Heat Pumps for Distillation Columns," *Chemical Engineering Progress*, June 1990, p. 60.

[110] *Chemyclopedia 91*, Vol. 9, American Chemical Society, 1991.

[111] ORNL, supra note 94

[112] Joseph Haggin, "Membrane Technology Has Achieved Success, Yet Lags Potential," *Chemical & Engineering News*, Oct. 1, 1990, p. 22.

[113] U.S. Department of Energy, *National Energy Strategy, Interim Report*, supra note 39.

The industrial sector has intensified its efforts to minimize waste and reduce emissions through process changes in order to attain environmental compliance in a cost-effective manner. For example, 3M Co. switched from a solvent-based to a water-based carrier in a tablet-coating operation.[114] Du Pont Co. cut its plastics waste disposal by 50 million lb/yr through tighter equipment and process controls and by finding markets for off-spec material. Air Products and Chemicals reduced its plants' emissions by over 90 percent, largely by recycling or substituting for solvents. In general, the industry has begun to emphasize that efforts aimed at waste minimization could also improve product yields.[115] Clearly, reduction in petroleum consumption is a potential added benefit, but no estimates of specific overall savings have been calculated.

Post Consumer Recycling

Because of the costs and environmental consequences from solid waste disposal, recycling of wastes has gained added significance. As an additional benefit, some recycling efforts could contribute to reduced oil consumption.

Recycled Plastics—In 1988, 10.3 million tons of plastics were discarded as MSW. Only about 1 percent, or 125,000 tons, was recycled.[116] Recently, several firms have announced plans to expand plastics recycling.[117] To the extent that these plans become successful in substituting or reducing the need for virgin plastics, they could lead to a corresponding decrease in oil consumption.

Redesigned Packaging—Replacing plastic packaging with biodegradable, nonpetroleum-based material has also been suggested as a way to reduce the environmental impacts of waste disposal. McDonald's Corp. has announced plans to switch from polystyrene to (ultimately recyclable) paper packaging.[118] Replacing nonrecycled with recycled plastic packaging has also been suggested as an alternative, but it is not clear how much oil, if any, this would save.

Used Oil—About 720 million gallons of used oil are recycled each year, mostly by burning it as fuel. Most of the remaining 400 million gallons represents the amount generated at households and then disposed of in the trash, on the ground, or down sewers. With proper education, incentives, and enforcement, the portion of such oil recycled might be increased. Reuse of this oil as fuel oil has been limited because of costs and technical problems, but it has been done.[119]

Used Tires—The mountains of used tires accumulated around America represent a resource that potentially could be tapped for materials or fuel.[120] Old tires can be burned as fuel—either directly or in a processed tire-derived fuel. Pulverized rubber from old tires can be added to asphalt. Efforts are under way to develop an 18-percent rubberized asphalt. If successful, such a ground rubber asphalt could not only consume more than 1,000 old tires in every lane mile,[121] but also reduce the Nation's asphalt and road oil consumption, which was about 450,000 B/D in 1989.[122] Efforts at increasing recycling or reuse of tires must confront the challenges of removing nonrubber belting and additives in a cost-effective way.

Use of Alternate Feedstocks

LPG and petrochemical feedstocks are used primarily to produce plastic resins, accounting for almost 30 percent of industrial petroleum consumption. It

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[114] A number of additional examples are presented in U.S. Congress, Office of Technology Assessment, *Serious Reduction of Hazardous Waste for Pollution Prevention and Industrial Efficiency*, OTA-ITE-317 (Washington, DC: U.S. Government Printing Office, September 1986), ch. 3.

[115] "Reducing Wastes can be Cost-Effective," *Chemical Engineering*, July, 1990, p. 31.

[116] U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?*, OTA-O-424 (Washington, DC: U.S. Government Printing Office, October 1989).

[117] Ann M. Thayer, "Solid Waste Concerns Spur Plastic Recycling Efforts," *Chemical & Engineering News*, Jan. 30, 1989, p. 7. "Plastics Recycling Expansion Planned," *Chemical & Engineering News*, Oct. 1, 1990, p. 5.

[118] "McDonald's to Drop Polystyrene Packaging," *Chemical & Engineering News*, Nov. 12, 1990, p. 5.

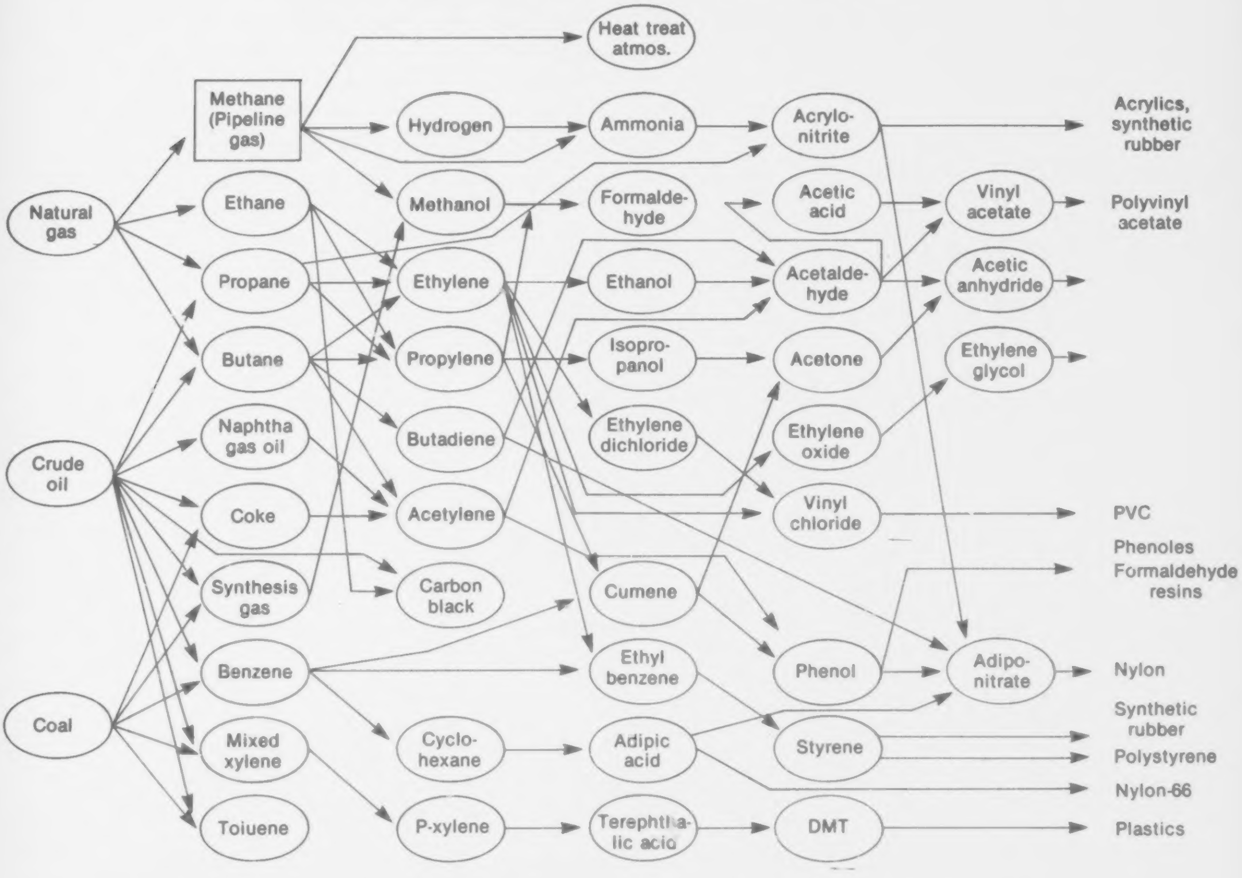
[119] Facing America's Trash, supra note 116.

[120] EPA estimates that about 250 million tires are discarded annually and that the stockpile of old tires could total 2 to 3 billion nationwide. Only about 30 percent of the tires discarded each year are recycled in some form. *Hearings on Scrap Tire Management and Recycling Opportunities* before the Subcommittee on Environment and Labor and the Subcommittee on Regulation, Business Opportunities, and Energy of the House Committee on Small Business, 101st Cong., 2d sess., Apr. 18, 1990.

[121] "Superior Materials are in the Offing," *Engineering News Record*, Oct. 4, 1990, p. 33. Such efforts to tap resources contained in old tires present a limited opportunity, however. If just 10 percent of U.S. annual needs for asphalt cement were required to be rubberized asphalt concrete, that use alone would exhaust almost all the tires discarded in a single year. Hearings, supra note 120, at p. 55.

[122] *Annual Energy Review 1989*, supra note 6.

Figure 3-9—Chemical Feedstocks: Sources and Applications


Natural gas
Crude oil
Coal
Methane (Pipeline gas)
Ethane
Propane
Butane
Naphtha gas oil
Coke
Synthesis gas
Benzene
Mixed xylene
Toiuene
Heat treat atmos.
Hydrogen
Methanol
Ethylene
Propylene
Butadiene
Acetylene
Carbon black
Cyclo-hexane
P-xylene
Ammonia
Formalde-hyde
Ethanol
Isopro-panol
Ethylene dichloride
Cumene
Ethyl benzene
Adipic acid
Terephtha-lic acid
Acrylo-nitrite
Acetic acid
Acetalde-hyde
Acetone
Ethylene oxide
Vinyl chloride
Phenol
Styrene
DMT
Vinyl acetate
Acetic anhydride
Ethylene glycol
Adipo-nitrate
Acrylics, synthetic rubber
Polyvinyl acetate
PVC
Phenoles Formaldehyde resins
Nylon
Synthetic rubber
Polystyrene
Nylon-66
Plastics

SOURCE: Office of Technology Assessment, 1991, adapted from U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983), figure 28, p. 117.

might be possible to use nat~~ural gas, coal, or~~ biomass to produce alternatives to oil-based feedstocks. In theory, it is possible to replace crude oil with natural gas in feedstock production, as shown in figure 3-9. Whether it can be economically feasible to do so will require additional study. At present, there are several examples of commercial ventures that use alternative feedstocks.

Eastman Chemicals Co. has been producing about 560 million lb/yr of acetic anhydride using Texaco's coal gasification technology. The plant, which went on line in 1984, uses about 900 tons/day of high-sulfur coal. Construction is currently underway to double the output by early 1992.[123]

Warner-Lambert Co. has announced that it will build a corn and potato starch-based plastics plant in Illinois. The 100 million lb/yr plant is scheduled to go on line by the end of 1991.[124]

Many ethylene plants are capable of operating on a wide range of hydrocarbon feedstocks; for example, some of the alternate feedstock requirements for 100 lb of ethylene are: 125 lb of ethane, 240 lb of propane, or 320 lb of naphtha.[125]

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[123] Calvin Anderson, Eastman Chemicals Co., personal communication to Renova Engineering, OTA contractor, Jan. 25, 1991.

[124] "Warner-Lambert Revs Up Starch-based Plastic," *Environment Today*, October 1990, p. 27.

[125] Bruce F. Greek, "Margins Plunge for Steam Cracker Ethylene and Coproducts," *Chemical & Engineering News*, Oct. 29, 1990, p. 14. Petroleum reduction estimated by Renova from the data reported in the paper.

The 1989 ethane and propane production was about 470,000 B/D each, while the natural gas production was about 17 trillion cubic feet (TCF).[126] Of the total ethane and propane used in the country, about one-third is derived from natural gas.[127] During a crisis, if natural gas production is increased by 1 TCF, ethane and propane supply would increase by about 9,000 B/D each. This increase could displace, in principle, about 35,000 B/D of naphtha.[128] The 1990 ethylene production is forecasted to be about 36 million lb.[129] Since some of the plants already use non-oil-based feedstocks and the feedstocks also determine the quantity of ethylene coproducts, a detailed study would be necessary to verify the actual potential.

Potential Savings

Based on the above discussion, we conclude that process changes would embrace a multitude of options. Each of the foregoing options could replace a small amount of petroleum on an individual basis, leading to a significantly larger collective potential. While we were not able to analyze each option in detail, we have assumed an optimistic scenario, wherein the overall replacement from these and other process changes is assumed to be about 100,000 B/D, or approximately 3 percent of the remaining petroleum consumption.

Deployment Considerations and Costs

A deployment schedule, based on such a scenario, is shown in table 3-19. We have assumed that reduced refinery throughput will decrease oil consumption in the first year. Similarly, about two-thirds of the natural gas conversions, corresponding to the DOE estimates of short-term fuel switching capability, will also occur in the first year. The remaining third of the natural gas conversions are assumed to occur uniformly over the 5-year period. Conversion to other fuels and process changes would become effective in the last 2 years as they generally would require longer lead times for construction.

Estimated capital costs for the various oil replacement options are shown in table 3-20. These investment costs are representative of oil replacement projects in the industrial sector and do not include the full range of replacement options. Minimum investments costs per barrel of oil replaced range from $0 for reduced refinery throughput, natural gas fuel switching in existing equipment, and some process changes to about $31,000 B/D for converting a 100,000 lb/hr steam boiler to use CSF. More extensive process changes and fuel conversions would be considerably more expensive. It is conceivable that some replacement options would result in net cost savings, but none are assumed here.

For reasons discussed at length in our 1984 report and background paper, the availability of manufacturing capacity and of engineering, technical, and craft personnel to convert industrial boilers to non-oil fuels is not expected to be an absolute constraint. As discussed later in this chapter, shortages of qualified engineering and craft personnel could result in some delays in completion of large-scale conversions and retrofits, however. It is also assumed that the necessary environmental permits for plant modifications and/or fuel conversion projects will be obtained relatively smoothly over a 12- to 18-month permitting process.

As discussed in the section on resource availability later, natural gas supplies and delivery capabilities are assumed to be adequate. Seasonal limitations currently exist on the deliverability of natural gas for some industrial users. To overcome these limits, some industrial and utility natural gas consumers are examining the possibility of constructing or reopening liquefied natural gas[130] plants and storage facilities to stockpile natural gas for continued use during periods of peak demand.[131]

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[126] "Warner-Lambert Revs Up Starch-based Plastic," supra note 124.

[127] *Short-Term Petroleum Fuel Switching*, supra note 16.

[128] Petroleum reduction estimated by Renova from the data reported in Greek, supra note 125.

[129] *Annual Energy Review 1989*, tables 159 and 71.

[130] Natural gas that has been turned into a liquid by cooling it to minus 260 °F at atmospheric pressure. Liquefaction allows natural gas to be more easily stored and transported long distances by ship.

[131] Discussions at OTA workshop, Dec. 5, 1990.

Table 3-19—Deployment Schedule for Oil Replacement Technologies in the Industrial Sector (oil replacement potential,thousand barrels per day)

Year	Reduced refinery throughput[a]	Fuel switching: Natural gas[b]	Fuel switching: Other fuels[c]	Process changes[c]	Total
1991	360	219	0	0	579
1992	360	238	0	0	598
1993	360	258	0	0	618
1994	360	277	25	50	712
1995	360	297	50	100	807

[a] Oil replacement occurs in the first year.

[b] About 75% oil replacement in the first year.

[c] Assumes uniform deployment in the last 2 years.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Table 3-20—Estimated Costs for Oil Replacement Technologies in the Industrial Sector

Option	$000 per B/D replaced[a]: Minimum	$000 per B/D replaced[a]: Maximum	Remarks
Reduce refinery throughput	0	0	
Natural gas	0	5	Minimum assumes existing equipment, maximum assumes that a replacement boiler rated at 25,000 lbs/hr steam costs $250,000 and it replaces an oil-fired unit operating at 75 percent efficiency and 40 percent capacity factor.
Other fuels	31	98	CSF conversion of a 100,000 to 400,000 lbs/hr steam boiler operating at a 40 percent capacity factor.
Process changes	0	20	LPG could displace naptha in ethylene plants at essentially zero cost. At the other extreme, assumes a $10 million retrofit cost for a heat pump add-on to a 250,000 tons/yr styrene plant to reduce oil consumption by 500 B/D[b] .

[a] Approximate investment cost in thousand 1990 dollars per barrel per day of oil replaced.

[b] A cost of $40 to $125 per lb/hr of steam derated output (1985 dollars) was cited in H.R. Beal et al.,"Coal-Water Fuel Retrofit Evaluations," paper presented at Coal—Targets of Opportunity Workshop, DOE, Washington, DC July 12 [illegible], 1988. This cost was increased by 30 percent to reflect 1990 dollars.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

TRANSPORTATION SECTOR

The transportation sector is the U.S. economy's largest oil user, accounting for almost 63 percent of the Nation's total oil consumption. In 1989 the transportation sector used about 10.8 MMB/D of petroleum products, more than twice as much as the second largest user (the industrial sector) and more than domestic oil production.[132] Over 80 percent of transport sector oil is consumed by motor vehicles (cars, trucks, and buses), about 14 percent is used by aircraft, and the rest is split between water and rail transport. Table 3-21 summarizes the 1989 oil consumption in the transportation sector.

The most promising opportunities for fuel savings in both the short- and long-term in this sector involve oil replacement options for automobiles and light trucks. These light-duty vehicles (LDVs) represent the largest number of vehicles on the road and well over half of transport oil use. Although one can expect continued incremental improvements in fuel efficiency in other motor vehicles and other modes of transportation, the short-term technical potential for reducing petroleum consumption there is relatively small, and no net savings are included in our estimates.

Oil Use in the Transportation Sector

Petroleum products supply over 95 percent of this sector's energy needs. The transportation system is basically locked into petroleum use for all but the long-term, and efforts to shift to alternate energy sources face significant hurdles. Transportation's share of total oil use has increased from 54 percent in 1979 to 63 percent in 1989. Since 1984, transport sector oil use has grown by 1.15 MMB/D. As transportation uses make up an even larger share of domestic energy use, U.S. flexibility to respond to oil supply and price disruptions has shrunk.

Motor vehicles consumed 8.8 MMB/D of oil in 1989, divided between passenger cars (about 4.9 MMB/D, or about 56 percent), and buses, trucks, and other vehicles (3.9 MMB/D). Aviation used about 1.5 MMB/D or about 14 percent of the total.

Energy consumption in the transportation sector is driven by five factors: technical potential, existing fleet characteristics, manufacturing capacity for replacement vehicles and retrofit equipment, consumer preference (i.e., for model size or horsepower, as influencing fleet replacements), and consumer behavior (miles driven, driving habits, other practices). Our analysis of technical options focuses primarily on the first three factors. Measures targeted at the last two factors could also result in (sizable) fuel savings. More than with any other sector, achieving fuel savings in the transportation sector is like hitting a moving target, because of the continuing growth in transportation demand and the importance of behavioral factors.

Oil Replacement Options for Light-Duty Vehicles

The major short-term oil replacement opportunities for LDVs are improved fuel efficiency, conversion of some fleet vehicles to natural gas and other alternate fuels, and better traffic management. Electric vehicles,[133] while offering significant promise, are not expected to contribute substantial fuel savings within the next 5 years. We estimate that these options could displace about 555,000 B/D of petroleum products, about 5 percent of the consumption in the transportation sector. This would be accomplished using existing technologies and with some shifts in customer preference and new-vehicle fleet mix favoring higher fuel efficiency. The estimated savings are highly contingent on manufacturers' willingness to accelerate dispersion of existing fuel economy technologies in the new vehicle fleet and consumer acceptance. Additional savings are possible with considerable effort if there is a major shift in consumer preferences toward smaller, more efficient models, and if manufacturers accelerate the use of available fuel saving technologies to more models in advance of current product plans.

Fuel Efficiency Improvement

We estimate that under our severe import disruption scenario the introduction of new, more fuel-efficient vehicles in the LDV fleet could reduce

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[132] *Annual Energy Review 1989*, supra note 6, table 62.

[133] Larry O'Connell, Electric Power Research Institute, personal communication to Renova Engineering P.C., OTA contractor, Oct. 12, 1990. "A Los Angeles Clean-Air Car," *The New York Times*, Monday, Sept. 10, 1990.

Table 3-21—Oil Consumption in the Transportation Sector, 1989

Transportation mode	Oil consumption MMB/D[a]	Vehicles[b] (millions)	Vehicle miles per year (thousands)[c]
Motor vehicles			
Passenger cars[d]	4.86	144.4	10.12
Others[e]	3.95	48.6	12.50
Subtotal[f]	8.81	193.0	10.72
Aircraft[g]	1.49		
Ships[h]	0.33		
Railroads[i]	0.22		
Total	10.85		

[a] Estimated breakdown from U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 62.
[b] Registered vehicles in 1989 from *Annual Energy Review 1989*, table 24.
[c] Assumes that the 1988 data for passenger cars and all motor vehicles from *Annual Energy Review 1989*, table 23 is valid for 1989. Mileage for other vehicles calculated by difference.
[d] Includes passenger cars only as reported by DOE. Assumes that passenger cars consumed 55.2% of the total for all motor vehicles, the ratio calculated for 1988 from *Annual Energy Review 1989*, tables 23 and 24.
[e] Other vehicles include about 44.2 million buses and trucks, and about 4.4 million motorcycles. Calculated consumption for other vehicles by difference.
[f] Includes motor gasoline, gasohol, distillate fuel oil (diesel oil), and LPG and kerosene, when used in highway vehicles.
[g] Assumes 100% of the jet fuel.
[h] Assumes 100% of the residual fuel.
[i] Equal to the total supply of 10.85 MMB/D of petroleum less consumption by all other sectors.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

overall fuel consumption by from 67,000 B/D to as much as 545,000 B/D over 5 years. This range in estimates of fuel savings are tied to different assumptions about the characteristics of the existing LDV fleet (e.g., size and fuel economy) and future changes (e.g., fuel economy and market share of new vehicles, fleet growth, and changes in vehicle miles traveled).

Although fuel efficiency has increased since 1973, these gains have eroded in recent years. From 1973 to 1988, fuel efficiency improved dramatically, with average fleet fuel economy increasing by about 50 percent from 13.5 mpg to 20 mpg.[134] Table 3-22 summarizes the historical fuel economy for LDVs. By 1987-88, sales-weighted new car fuel economy had increased to over 28 mpg. These gains were not as great as they could have been, however, from 1984 through 1988 consumers sought more luxury options and performance in cars at the expense of fuel economy.[135] Moreover, light trucks, including minivans and sport/utility vehicles (i.e., 4x4's and other machomobiles) became more popular; by 1989 they comprised about one-third of the combined passenger car and light truck sales. The fuel economy of new light trucks showed a smaller gain than that of cars, reflecting the increased market share of less fuel efficient small vans and small utility vehicles[136] These factors, combined with an increase in average fleet age to about 8 years,[137] limited the 1984 to 1988 gain in onroad miles per gallon to about 7 percent. The LDV data for 1989 and 1990 model years shows an actual decline in the fuel economy compared with the 1988 model units.[138]

OTA estimates that in the absence of a crisis, the 1995 model year car fleet could attain a fuel economy of about 32 to 33 mpg (EPA rating) if each automobile manufacturer applies existing technology to improve

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[134] Stacy C. Davis and Patricia S. Hu, *Transportation Energy Data Book: Edition 11*, ORNL 6649, (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991), tables 3.18 and 3.8.

[135] *National Energy Strategy, Interim Report*, supra note 39.

[136] Linda S. Williams, and Patricia S. Hu, "Light-Duty Vehicle MPG and Market Shares Report: Model Year 1989," Oak Ridge National Laboratory, ORNL-6626, 1989.

[137] *National Energy Strategy, Interim Report*, supra note 39.

[138] *Transportation Energy Data Book: Edition 11*, supra note 134, figure 3-33.

Table 3-22—Fuel Economy Data for Light-Duty Vehicles, 1984-90

	1984	1988	Percent change 1984 - 88	1989	1990 6-months
New light-duty vehicles sold[a]					
Automobiles	10.2 million	10.4 million	2.0%	10.1 million	4.3 million
Light trucks	3.6 million	4.7 million	30.6%	4.8 million	2.2 million
Total	13.8 million	15.1 million	9.4%	14.9 million	6.5 million
Fuel economy					
New vehicles (EPA)[a]					
Automobiles	26.3 mpg	28.5 mpg	8.4%	28.0 mpg	27.7 mpg
Light trucks	20.0 mpg	20.7 mpg	3.5%	20.2 mpg	20.6 mpg
Total new fleet	24.3 mpg	25.5 mpg	4.9%	25.0 mpg	24.8 mpg
On road fuel economy all light-duty vehicles[b]	16.4 mpg	17.5 mpg	6.6%	NA	NA

NA = Not Available.

[a] Includes automobiles and light trucks. Model year new vehicle sales and EPA fuel economy data from Linda S. Williams and Patricia S. Hu, "Light-Duty Vehicle Summary: First Six Months of Model Year 1990," ORNL-6626/S1, Oak Ridge National Laboratory, July 1990.

[b] Includes cars and light trucks. On-road mpg data from U.S. Department of Energy, Energy Information Administration, *Energy Conservation Trends—Understanding the Factors That Affect Conservation Gains in the U.S. Economy*, DOE/PE-0092, September 1989, table 16, app. A. The efficiency of all light-duty vehicles would be 15 to 20 percent higher, if expressed in terms of EPA mpg which is a laboratory-based measure of fuel economy.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

its fuel economy according to the technological potential of its fleet and assuming a new fleet mix comparable to 1990.[139] Mechanisms for this shift in fuel economy trends could be in the form of direct requirements on auto fuel efficiency through revised Corporate Average Fuel Efficiency (CAFE) standards, increased gas guzzler taxes, or, most unlikely, a sudden enlightenment about and dedication to fuel efficiency among auto industry executives. The 1995 new car fleet economy could be even greater if buyer preferences changed significantly in response to, for example, higher oil prices or anticipated gasoline shortages, resulting in a shift in sales toward smaller, less powerful cars and/or to more fuel-efficient models within size classes.[140] Without dramatic shifts in manufacturers' perceptions of consumer preferences, substantially higher oil prices, or changes in fuel economy standards, OTA estimates that new car fleet fuel economy under the manufacturers' business as usual product plan will be only about 29 mpg by 1995.[141]

OTA estimates that 1995 model year light trucks could attain a fuel economy of about 24 mpg. Assuming that new light trucks continue to account for one-third of all new LDV sales, the fuel economy for the total new 1995 LDV fleet would be about 29 mpg.[142] Compared with the 1990 new fleet fuel economy of about 25 mpg (see table 3-22), this would amount to an average increase of about 3 percent per year.

Achieving these efficiency gains is contingent on automobile manufacturers making more efficient vehicles and on consumers buying them. Under normal circumstances, automobile manufacturers will have already put into place their design and production plans and schedules for model years 1991 through 1995 based on the anticipated market demand. Supplier contracts will be out for bid and negotiation. Radically altering these schedules to produce a different mix of vehicles or to accelerate introduction of more efficient technologies could cause financial, logistical, and legal headaches. Of course, disastrous

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[139] See U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, expected to be published in October 1991. This OTA report examines the technical potential of various fuel economy technologies and alternative government standards. Interim results were presented in congressional testimony. Steven E. Plotkin, "Estimating Levels of Corporate Average Fuel Economy,'' testimony before the Senate Committee on Energy and Natural Resources, Mar. 20, 1991. Steven E. Plotkin, Senior Associate, U.S. Congress, Office of Technology Assessment, "Legislative Proposals to Increase Automotive Fuel Economy and Promote Alternative Transportation Fuels," testimony before the Subcommittee on Energy and Power of the House Committee on Energy and Commerce, Apr. 17, 1991.

[140] Oak Ridge National Laboratory, supra note 94.

[141] Steven E. Plotkin, supra note 139.

[142] Steven E. Plotkin, Senior Associate, U.S. congress, Office of Technology Assessment, "Increasing the Efficiency of Automobiles and Light Trucks—A Component of a Strategy to Combat Global Warming and Growing U.S. Oil Dependence," presentation before the Consumer Subcommittee, Committee on Commerce, Science, and Transportation, U.S. Senate, May 2, 1990.

Table 3-23—Alternate Scenarios for Efficiency Gain in the Light-Duty Vehicle Fleet, 1991-95

	Efficiency gain		
	Low	High	Notes
Average new sales, million units/year	10.0	12.0	a
Average fleet growth, percent per year	1.0	0.0	b
New vehicle fuel economy, EPA mpg			c
1991 model year	25.0	25.0	
1995 model year	30.4	33.4	

[a] Assumes 30 and 10 percent declines respectively from the 1990 sales of 13 million units.

[b] The 1984-88 growth rate was about 2 percent per year based on DOE's data on registration of passenger cars, U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990). The low gain scenario assumes half of this rate. The high gain scenario assumes no growth based on an intensified retirement of older cars by consumers.

[c] Assumes that the 1991 new LDV fleet fuel economy is same as that in 1991. Assumes an annual increase of 5 and 7.5 percent, respectively. The resulting 30.4 mpg in 1995 implies a reduced market share for light trucks at a level of about 20 percent using OTA's 1995 estimates. The 33.4 mpg in 1995 implies a major shift towards smaller cars and much lower sales of light trucks.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

car sales from offering only gas-guzzling powercars can also produce manufacturer headaches and, manufacturers obviously must maintain some flexibility to modify product lines and options. During an oil supply shortfall, the major option available to manufacturers would be to shift existing production capacity toward the most fuel-efficient configurations for each model.

The actual oil savings from a shift in new-vehicle fuel efficiency also depends on consumer behavior, such as vehicle miles traveled per year, market share of light trucks, total new vehicle sales, and growth in the overall LDV fleet. Different assumptions about these factors can yield considerable differences in estimates of improved auto fuel efficiency and oil savings. To reflect these uncertainties, we used two alternate scenarios—low-efficiency gain and high-efficiency gain—to assess the fuel savings from fleet turnover for the 1991 to 1995 period. The key assumptions used in these scenarios are shown in table 3-23.

Both scenarios assume 1) an existing 1988 LDV fleet of 160 million vehicles with an onroad fuel economy of 17.5 mpg[143] and (2) a fleet growth of 2 percent per year between 1988 and 1990. Based on these two assumptions and new-model year sales data for 1989 and 1990 (table 3-22), we estimate the 1990 LDV fleet size to be about 167 million vehicles, with an on-road fuel economy of about 18 mpg.[144] We have also assumed the vehicle miles traveled to be 10,100 miles per vehicle per year, the average reported by DOE for passenger cars in 1988 (table 3-21).

The low-efficiency gain scenario corresponds to a slight improvement in the new fleet fuel economy based on renewal of past efficiency gains, depressed new car sales, a modest growth in the fleet size, and a reduced market share for light trucks. The high-efficiency gain scenario corresponds to a more substantial improvement in the new fleet fuel economy, a modest decline in new car sales, zero growth in the fleet size, reduced market share for light trucks and a major shift towards lighter more fuel-efficient cars.

Our analysis, shown in table 3-24, indicates that in 5 years, under the low-efficiency gain scenario, the LDV fleet could save about 67,000 B/D. In contrast, under the high-efficiency gain scenario, shown in table 3-25, which assumes a 34-percent improvement in fuel economy, the LDV fleet could save about 545,000 B/D over 5 years. We have used a mid-range value of 300,000 B/D as the potential fuel savings.

The potential mid-range savings of about 300,000 B/D from the turnover in the LDV fleet is significantly less than the 1984 OTA estimate of 700,000-800,000 B/D.[145] The 1984 study assumed that in a crisis, the new-car fuel efficiency could be increased from 27.5 to 36 mpg, or a gain of about 31 percent. The primary reason for the difference is that under the updated scenarios, the new 1991-95 cars are replacing old cars that are, on average, more fuel efficient

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[143] This reflects a lower miles per gallon value than DOE estimate. We have used the Motor Fuel Consumption (MFC) Model estimate of about 160 million LDVs in 1988 as the basis for our estimates. The data on the number of registered vehicles in the country are not consistent. For example, DOE indicates that in 1986, about 181.5 million vehicles were registered, consisting of 135.4 million passenger cars, 5.3 million motorcycles, and 40.8 million buses and trucks, *Annual Energy Review 1989*, supra note 6, table 24. On the other hand, the MFC Model used by DOE for evaluating the impact of conservation policies, indicates a total 1986 fleet of 162.1 million vehicles, consisting of 117.3 million passenger cars, 37.1 million light trucks with Gross Vehicle Weight (GVW) of less than 8,500 lb each, and 7.8 million heavy trucks (GVW > 8,500 lb). Energy and Environmental Analysis, Inc., "The Motor Fuel Consumption Model, 14th Periodical Report," prepared for Martin Marietta Energy Systems, Inc., app. B, Dec. 15, 1988.

[144] This estimate is lower than that for passenger cars published by DOE in its *Annual Energy Review 1989*, supra note 6.

[145] OTA, *The Oil Replacement Capability*, supra note 1.

Table 3-24—Low Efficiency Gain Scenario, 1991-95 Efficiency Improvement for the Light-Duty Vehicle Fleet

	Millions of light-duty vehicles			Vehicle fuel efficiency		Fuel use	Fuel savings	
Year	Total[a]	New[b]	Old[c]	New LDVs[d] EPA mpg	All LDVs[e] on-road mpg	Billion[f] gal/year	Billion gal/year	Thousand B/D
1988	160.0	15.1	144.9	25.5	17.5	—	—	—
1989	163.2	14.9	148.3	25.0	17.7	—	—	—
1990	166.5	13.0	153.5	24.8	17.9	94.0	base year	
1991	168.1	10.0	158.1	25.0	18.0	94.2	(0.28)	(18.24)
1992	169.8	10.0	159.8	26.3	18.2	94.3	(0.02)	(1.56)
1993	171.5	10.0	161.5	27.6	18.4	94.0	0.22	14.32
1994	173.2	10.0	163.2	28.9	18.7	93.6	0.45	29.24
1995	175.0	10.0	165.0	30.4	19.0	92.9	0.66	43.09
Total savings after 5 years								66.85

LDVs = Light-duty vehicles

[a] Assumes 160 million LDVs in 1988 and a 2 percent per year increase in fleet size from 1988 to 1990 and 1 percent per year thereafter.

[b] 1988 and 1989 data from table 3-22. Assumes 1990 new car sales at 13 million units and 10 million units/yr thereafter.

[c] Calculated by subtracting new vehicles from total.

[d] 1988, 1989 and 1990 data from table 3-22. Assumes that 1991 model year cars have the same EPA rating as that of the 1988 model year (table 3-22) and there is a 5 percent increase per year beyond 1991.

[e] Based on the 1988 on-road mpg for all cars at 17.5 mpg. For new vehicles, assumes that the on-road mpg is 80 percent of EPA mpg.

[f] Assumes 10,100 miles/car per year.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

than those replaced over the 1985-90 scenario in our earlier report. Other factors also have contributed to this difference. In 1984 we assumed continued progress in fuel efficiency. The CAFE standards have not been raised beyond 1985 and in fact were rolled back from 27.5 to 26 mpg for the 1986 to 1988 period. Perceived consumer demands for power and luxury resulted in production decisions favoring these options at the expense of fuel economy. Also, the market share of less fuel-efficient light trucks and vans increased substantially.

Conversion to Natural Gas

Currently, about 30,000 vehicles in the United States and 700,000 worldwide run on compressed natural gas (CNG).[146] Interest in natural gas vehicles (NGVs) has increased significantly in recent years, with major auto manufacturers announcing plans to market NGVs commercially.[147] For example, General Motors plans to offer 1,000 new natural gas-powered light trucks in California, Texas, and Colorado by 1991.[148] Most of the existing NGVs are gasoline-powered vehicles that have been retrofitted to burn natural gas, and most still retain a dual-fuel capability. Expanded sales of new NGVs and the conversion of more existing vehicles to natural gas offers a promising opportunity for replacing 130,000 B/D of oil in the near term.

The fleet vehicle market offers perhaps the greatest potential for natural gas conversions to cut oil use. Fleet vehicles include buses, trucks, local delivery vans, and police, government, and public utility vehicles. About 16 million vehicles are part of fleets of 10 or more vehicles.[149] We estimate that about 12

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[146] U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-354 (Washington, DC: U.S. Government Printing Office, September 1990) (hereinafter *Replacing Gasoline*), p. 97. This includes Italy (300,000), Australia (>100,000), New Zealand (150,000), and Canada (15,000).

[147] American Gas Association, "Outlook for Gas Energy Demand: 1990-2010," May 1990; and Robert Fani, Brooklyn Union Gas Co., personal communication to Renova Engineering, P.C., OTA contractor Oct. 15, 1990.

[148] Wald, "Proposals for a U.S. Energy Policy: Some Possible, Most Not," *The New York Times*, Monday, Sept. 24, 1990. "Bright Hopes for the Blue Flame," *Time*, Sept. 24, 1990, p. 68.

[149] American Gas Association, supra note 147.

Table 3-25—High-Efficiency Gain Scenario, 1991-95 Efficiency Improvement for the Light-Duty Vehicle Fleet

	Millions of light-duty vehicles			Vehicle fuel efficiency		Fuel use	Fuel savings	
Year	Total[a]	New[b]	Old[c]	New LDVs[d] EPA mpg	All LDVs[e] on-road mpg	Billion[f] gal/yr	Billion gal/yr	Thousand B/D
1988	160.0	15.1	144.9	25.5	17.5	—	—	—
1989	163.2	14.9	148.3	25.0	17.7	—	—	—
1990	166.5	13.0	153.5	24.8	17.9	94.0	base year	
1991	166.5	12.0	154.5	25.0	18.0	93.2	0.79	51.6
1992	166.5	12.0	154.5	26.9	18.3	91.9	1.27	82.7
1933	166.5	12.0	154.5	28.9	18.6	90.2	1.71	111.7
1994	166.5	12.0	154.5	31.1	19.1	88.1	2.11	137.9
1995	166.5	12.0	154.5	33.4	19.6	85.6	2.46	160.7
Total savings after 5 years								544.6

LDVs = Light-duty vehicles

[a] Assumes 160 million LDVs in 1988 and a 2 percent per year increase in fleet size from 1988 to 1990 and 0 percent per year thereafter.

[b] 1988 and 1989 data from table 3-22. Assumes 1990 new car sales at 13 million units (table 3-22) and 10 million units/yr thereafter.

[c] By difference.

[d] 1988, 1989 and 1990 data from table 3-22. Assumes that 1991 model year cars have the same EPA rating as that of the 1988 model year (table 3-22) and there is a 7.5 percent increase per year beyond 1991.

[e] Based on the 1988 on-road mpg for all cars at 17.5 mpg. For new vehicles, assumes that the on-road mpg is 80 percent of EPA mpg.

[f] Assumes 10,100 miles/car per year.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

million of these vehicles are cars, pickups, vans, and minivans.[150] We further estimate that these fleet LDVs used about 1.3 MMB/D of fuel in 1989.[151] In 1983, fleet automobiles averaged about 30,000 mi/yr compared with about 10,000 mi/yr for household automobiles.[152]

The attractiveness of fleet vehicles as conversion targets rests on two characteristics: central refueling capability and high annual mileage, which allows for quicker payback on the investment than for most private cars.

Switching fleet LDVs to run on natural gas entails two changes. First, the vehicle must be retrofitted to burn natural gas, and an onboard gas storage tank must be installed. Second, and perhaps more critical for successful penetration of NGVs, the vehicles must have a network to provide for refueling and servicing. Many, but not all, fleet vehicles use a central refueling location that could be equipped to refill their tanks with natural gas. However, a considerable number of fleet vehicles in fact refuel at commercial gasoline stations.[153] Nevertheless, it is possible for a network of central fleet refueling operations and commercial gas stations to be deployed to support the introduction of NGVs.[154]

Recent experience in British Columbia confirms the technological feasibility and economic attractiveness of fleet vehicle conversions.[155] In British Columbia, a small retail gasoline company began converting fleet vehicles to natural gas to stimulate sales of batteries and tires. Taxis were the first to accept the conversion. With an annual fuel consumption of over 1,500 gal per vehicle, the fleet owners recovered the conversion cost in less than 2 years. Sensing an opportunity, major oil companies also entered the market, and the refueling network grew from the original 20 stations to about 50 refueling stations serving fleet and private vehicles.[156]

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[150] This estimate assumes that the breakdown of the fleet by the type of vehicles is similar to that reported for the 1985 fleet population, Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 9*, ORNL 6325 (Oak Ridge, TN: April 1987), figure 2.14.

[151] This is based on an assumption that fleet vehicle fuel consumption is still reflects the 1983 ratio. In 1988, the 157.5 million private cars used a total of about 82.4 billion gallons of fuel, or about 5.4 million bbls/day. *Annual Energy Review 1989*, supra note 6, table 22.

[152] *Transportation Energy Data Book: Edition 9*, supra note 150, tables 2.28 and 2.34.

[153] *Replacing Gasoline*, supra note 146.

[154] Ibid., and Gas Research Institute, supra note 61.

[155] Patrick L. McGeer and Enoch J. Durbin, "Natural Gas in Cars—And Step On It," *The New York Times*, Friday, Sept. 14, 1990.

We have assumed that in response to an oil supply crisis, about 10 percent of the fleet LDVs could be converted to natural gas by 1995. This would require converting about 1.2 million vehicles at an average conversion rate of 240,000 vehicles per year. The converted vehicles would consume about 0.25 quads of gas per year and displace about 130,000 B/D of oil.[157] This would involve a 40-fold increase in U.S. CNG vehicles in just 5 years, no small task. The 10-percent penetration in the fleet population is comparable to that achieved in New Zealand.[158]

In our 1984 report, we estimated that every 1 million vehicles converted would require about 50,000 compressors for refueling stations, each rated at 20 standard cubic feet per minute (SCFM).[159] If, however, the average compressor size is increased to 50 SCFM to serve larger fleets, the required units would decrease to about 20,000 per million vehicles. Thus, a conversion of 10 percent of the fleet LDVs would require 24,000 to 60,000 compressors over a 5-year period.

Delivery constraints for storage cylinders and compressors could pose a potential limitation on this rate of conversion. The Department of Transportation (DOT) certifies the manufacture of storage cylinders. Currently, there are some delays for cylinders because of the lack of vendors with proper DOT certification.[160]

The peak production rate of 5,770 gas compressors occurred in 1974.[161] The currently estimated need is for 5,000 to 12,000 units per year. This has led potential customers to look at foreign sources. Italy, for example, with over 300,000 NGVs on the road, has a large base of cylinder manufacturers. Some gas utilities are already planning to test compressors offered by foreign vendors.[162] U.S. compressor technology is somewhat outdated, and currently, the units available from the United Kingdom are considered to be superior.[163] It is assumed that in a crisis the industry would intensify production efforts and the required compressors would be made available. Given a demand, U.S. companies that manufacture large-diameter pressure piping could fabricate the required cylinders.[164]

Conversion to Other Fuels

An oil supply shortfall would also stimulate use of alternative fuels that would replace or be mixed with gasoline. Over the relatively short replacement horizon considered here, synthetic fuels—such as oil from oil shale or coal liquefaction, even if commercially ready—would not make a significant contribution because of time needed to site, permit, and construct such facilities. The primary short-term alternative fuels are various alcohol fuels, either neat (alone) or blended with gasoline. Currently available fuels include gasohol, a gasoline/alcohol blend (90 percent gasoline, 10 percent ethanol); a substantially pure alcohol, such as neat methanol; and so-called M-85 (85 percent methanol, 15 percent gasoline), an alcohol/gasoline blend that is predominantly alcohol. "Oxygenated fuels" comprise about 25 to 30 percent of the gasoline sold in the country.[165] They contain gasoline blended with low amounts of alcohols or other oxygen-containing compounds, such as methyl tertiary butyl ether (MTBE), and tertiary amyl methyl ether (TAME).

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[156] Enoch Durbin, personal communication to Renova Engineering, OTA contractor, Nov. 8, 1990.

[157] The published data on the near term potential for converting U.S. fleet vehicles to natural gas is limited. For example, an analysis by the American Gas Association (AGA) estimates that NGVs could consume 0.7 quads by the year 2000 under two alternate scenarios - "low energy use" corresponding to significant energy conservation and high environmental standards, and "high environment/high demand use" corresponding to high environmental standards and moderate energy conservation. In its forecast AGA assumed that the major market penetration would occur beyond 1995. American Gas Association, "The Outlook for Gas Energy Demand: 1990-2010," May, 1990. Assuming that 5 to 10 percent of AGA's year 2000 projection could be achieved by 1995, it would indicate a conversion rate of about 35,000 to 70,000 vehicles per year.

[158] Enoch Durbin, supra note 156.

[159] OTA, *The Oil Replacement Capability*, supra note 1.

[160] Fani, supra note 147.

[161] Office of Technology Assessment, *The Oil Replacement Capability*, supra note 1.

[162] Fani, supra note 147.

[163] Durbin, supra note 156.

[164] Durbin, supra note 156.

[165] American Institute of Chemical Engineers, "Methanol and Ethanol as Alternate Fuels for Motor Vehicles," April 1990.

Gasohol now holds about 8 percent of the gasoline market, and therefore the current consumption of ethanol as a fuel is estimated to be about 54,000 B/D, or about 825 million gals/yr. Most of this ethanol is derived from corn.[166] Ethanol does not replace oil on a gallon-for-gallon basis. Because ethanol has an energy content of 75,700 Btu/gal, compared with gasoline's 125,000 Btu/gal,[167] the 50,000 B/D of ethanol now used actually displaces about 30,000 B/D of gasoline.

At present there is excess domestic ethanol production capacity of about 475 million gal/yr, comprising 375 million gal/yr of corn-based and 100 million gal/yr of synthetically produced ethanol.[168] If, in a crisis, available capacity could be expanded by constructing five new corn-based ethanol plants, each rated at 50 million gal/yr, sufficient ethanol would be available to displace an additional 700 million gal/yr, equivalent to 25,000 B/D of gasoline.

Natural gas feedstocks provide most of current methanol needs, but technology exists to derive methanol from coal and biomass.[169] Of the 1,380 million gal/yr of methanol consumed in the country, about 85 percent is used as a feedstock in the production of other chemicals, mainly formaldehyde, acetic acid, and chloromethane. DOE estimates that about 280 million gal/yr of methanol, about 20,000 B/D, are used as fuel additives.[170] At an energy content of 56,600 Btu/gal,[171] compared with gasoline's 125,000 Btu/gal,[172] the 20,000 B/D of methanol in current use displaces about 9,000 B/D of gasoline.[173]

Because of the recently enacted Federal Clean Air Act amendments and the changes proposed by the California Air Resources Board, the demand for MTBE is expected to rise dramatically.[174] Methanol is the feedstock for MTBE. Since no new methanol plants are under construction, the supply of methanol could be a limiting factor by the mid-1990s.[175] We do not assume the construction of any new domestic gas-based methanol plants.

In an oil crisis, it could be possible to shift methanol uses from other uses to MTBE. It might also be possible to import gas-based methanol from countries with large gas reserves. We have, however, not included the oil displacement potential of these options because of the uncertainty in supply. Moreover, given the long lead-time required, we have also excluded the feasibility of building any new domestic coal-based methanol plants. In short, we have assumed a negligible oil displacement potential for methanol during the crisis.

Improvements in Traffic Management

Motor vehicle fuel efficiency goes down at both low and very high speeds. Therefore, efforts at improving traffic management to promote more efficient vehicle travel could make modest contributions to saving oil. Various mechanisms have been suggested for improving the use of existing transportation capabilities. We have focused only on relatively passive or voluntary methods and do not include direct means to constrain driver behavior (other than enforcing existing 55 mph, speed limits), such as restrictions on vehicle use or gas purchases, parking bans, and similar measures. Each of these measures alone offers only limited fuel savings, but taken together they could save 100,000 B/D—equal to other options considered here.

In a crisis the Nation could adopt further measures aimed at improving traffic efficiency and management. Examples of such measures are as follows:

Reduced Highway Speed Limits—The fuel economy of an automobile changes with its speed. Test results on 15 different vehicles of 1981-83 model years that were equipped with 4-, 6- and 8-cylinder gasoline and diesel powered engines indicate a wide variation in fuel economy at speeds between 15 and 65 mph. The average data for the 15 cars showed an increase in fuel economy from about 26 mpg at 65 mph to about 31 mpg at 55 mph.[176] We estimate that a reduction in the highway speed limit to 55 mi/h would reduce fuel consumption by about 60,000 B/D, provided that the speed limit is enforced strictly.[177]

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[166] *Short-Term Petroleum Fuel Switching*, supra note 16.

[167] ORNL, *Energy Technology, What Could Make a Difference?*, supra note 17, table 1.1-1, p. 10.

[168] *Short-Term Petroleum Fuel Switching*, supra note 16.

[169] *Replacing Gasoline*, supra note 146.

[170] *Short-Term Petroleum Fuel Switching*, supra note 16.

[171] Ibid.

[172] *ORNL Energy Technology R&D: What Could Make a Difference?*, supra note 17, table 1.1-1, p. 10.

[173] *Short-term Petroleum Fuel Switching*, supra note 16.

[174] Gerald Parkinson, "Shortages Slow, but Cannot Stop Gasoline Reformulating," *Chemical Engineering*, October 1990, p. 56.

[175] "Growth in Methanol Supply Lags Demand," *Chemical & Engineering News*, Sept. 3, 1990, p. 17.

Increased Use of Ride Sharing and High Occupancy Vehicle Lanes—A 1985 report on 13 high-occupancy vehicle (HOV) lane highways showed an annual saving of 50,000 to 150,000 gal of fuel during peak periods per HOV lane mile. In six projects, the number of ridesharing vehicles increased by 25 percent to over 300 percent, while vehicle occupancy showed an increase of 3 to 15 percent. Shirley Highway in Virginia showed an increase of over 1,000 percent in the number of ridesharing vehicles and over 200 percent in vehicle occupancy.[178] HOV lanes also reduce commuting time by 40 to 50 percent on highly congested highways.[179]

In an oil crisis, additional HOV lanes could promote more ridesharing. For example, one vanpool could replace up to 15 automobiles and save a significant amount of fuel even given the lower fuel economy of vans compared with that of automobiles.[180] The American Council for an Energy-Efficient Economy (ACEEE) estimates that using HOV lanes in cities with populations in excess of 500,000 could reduce fuel consumption by 11,000 to 40,000 B/D.[181]

Employers could further encourage ridesharing by offering preferential parking, flexible schedules, and guaranteed ride-back incentives for emergencies.[182] Existence of free parking is a deterrent against carpooling. A study in downtown Los Angeles indicates that in one case increased parking fees reduced single occupancy vehicles by 25 percent.[183] Such steps combined with improvements in traffic patterns would reduce traffic congestion.

A detailed study would be necessary to estimate the potential fuel reduction from more HOV lanes. We have assumed a savings of about 15,000 B/D based on establishing 100 to 150 HOV lane highways of 10 miles each, for an average saving of 150,000 to 200,000 gallons per lane mile.

Reducing Traffic Congestion—It is estimated that in 1987 traffic congestion increased consumption of gasoline by about 2.2 billion gallons, about 144,000 B/D.[184] In the absence of a detailed study, we have assumed that reduced traffic congestion could lead to a savings of 15 to 20 percent, or about 25,000 B/D.

Limited Oil Replacement Potential in Other Transport Sectors

While there have been significant gains in fuel efficiency in aviation, motor freight, and railroads over the past 2 decades, the gains have not been as dramatic as those for LDVs. Moreover, increasing fuel savings have been more than offset by growth in use of these transport modes. We believe that the short-term potential for reducing petroleum consumption in other modes of transportation is relatively small and therefore exclude these modes from our analysis for reasons briefly set out below. At the same time, we believe that modest fuel efficiency improvements in these sectors will continue and that a crisis may reduce fuel demand through a combination of cost-induced conservation, mode shifts, and changing demand for services resulting from associated economic impacts. These shifts, however, are not quantified.

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[176] *Transportation Energy Data Book: Edition 9*, supra note 159, table 2.21.

[177] In 1985, there were about 376 million highway trips with an average trip distance of 730 miles. These household trips involved the use of automobiles, trucks, and recreation vehicles. Moreover, vehicles which were less than 5 years old accounted for almost 60 percent of the travel miles. *Transportation Energy Data Book: Edition 9*, supra note 150, tables 2.23 and 2.8.

[178] *Transportation Energy Data Book: Edition 9*, supra note 150, tables 2.32 and 2.33.

[179] Stacy C. Davis et al., *Transportation Energy Data Book: Edition 10*, ORNL-6565 (Oak Ridge, TN: Oak Ridge National Laboratory, September 1989), table 3-44, p. 3-75.

[180] Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 9*, supra note 150, tables 2.23 and 2.8.

[181] Monica C. Burke, "High-Occupancy Vehicle Facilities: General Characteristics and Fuel Savings," American Council for an Energy-Efficient Economy, September 1989.

[182] Sandra Spence, Association for Commuter Transportation, personal communication to Renova Engineering, P.C., OTA contractor, Nov. 13, 1990.

[183] Ibid.

[184] *National Energy Strategy, Interim Report*, supra note 39, p. 14.

Table 3-26—Estimated Oil Replacement Potential in the Transportation Sector

Option	Estimated oil replacement potential—thousand B/D	Remarks
Improved fuel efficiency	300	Based on turnover in light-duty vehicle fleet by more efficient new cars. (range of about 67,000 B/D to 545,000 B/D)
Conversion to natural gas	130	Based on conversion of 10 percent of fleet LDVs.
Conversion to other fuels	25	Increased use of ethanol.
Improved traffic efficiency and management	100	Adoption of various measures for promoting fuel saving.
Total	555	

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Highway freight transportation has seen modest gains in fuel efficiency. There is less potential for improvements in fuel economy because the options of reducing the weight or power are not readily available. Engines of heavy trucks are already designed more for fuel economy than performance.[185] Nevertheless, some incremental savings can still be achieved through improved aerodynamics, improved tire designs, and development of low-heat rejection engines. Operational changes such as improved maintenance, less idling, and the limiting of empty backhauls can also provide some fuel savings.

Aircraft consumed 1.5 MMB/D of jet fuel in 1989. Commercial aviation accounted for 76 percent; general aviation, 4 percent; and Department of Defense peacetime uses, 20 percent.[186] Significant reductions in military fuel consumption, even during peacetime, are probably unlikely during an imported oil supply disruption.[187] Fuel savings in commercial and general aviation have been more than offset by increases in passenger travel and air freight.

Airline travel has been the fastest growing mode of passenger travel.[188] At the same time, more fuel-efficient jet aircraft are replacing older, less fuel-efficient planes as airlines seek to cut costs. This has helped aviation fuel consumption grow at a slower rate than passenger and freight miles traveled.[189] It is possible that during a crisis airline passenger travel could decline, cutting fuel consumption, but we have assumed that such a decline would not appreciably change the total consumption of about 1.2 MMB/D.

Waterborne shipping and railroads consumed an estimated 550,000 B/D in 1989, or about 5 percent of the consumption in the transportation sector. Domestic shipments accounted for over 50 percent of the tonnage shipped by water. Of this amount, over 62 percent were coal and petroleum products. These energy products also accounted for over 45 percent of the tonnage shipped by freight railroads.[190] Any decrease in domestic petroleum shipments during an oil crisis will be offset at least somewhat, perhaps more, by increased coal shipments. Hence, we have assumed that there will not be any appreciable change in the total consumption of about 550,000 B/D. Table 3-26 summarizes the breakdown of the estimated 555,000 B/D of oil that could be replaced in the transportation sector by the various options assessed above.

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[185] ORNL, *Energy Technology: What Could Make a Difference?*, supra note 17, p. 3-4.

[186] *Annual Energy Review 1989*, supra note 6, table 10. Percentage distributions estimated from 1987 data in ORNL *Energy Transportation Data Book: Edition 10*, supra note 179, table 2.8, p. 2-14.

[187] Military fuel needs in the Persian Gulf were largely met by local production and imports. If significant refinery capability in Saudi Arabia and other Gulf states were damaged, imports of jet fuel, gasoline, and distillates might have been needed to supply coalition forces and local needs.

[188] ORNL, *Energy Technology R&D: What Could Make a Difference?*, supra note 17, p. 5.

[189] Ibid. Between 1982 and 1988, fuel consumption grew 44 percent. Passenger miles traveled grew over 8 percent per year, and air freight increased over 9.5 percent per year. FAA projects air travel to grow at 5 percent per year to the year 2000. Between 1970 and 1988 passenger air traffic tripled, while fuel consumption grew only 43 percent. At least part of the doubling in seat mpg of efficiency was due to more seats per aircraft and higher load factors.

[190] ORNL, *Energy Transporation Data Book 9*, supra note 150, tables 3.5, 3.10., and figure 3.4..

Table 3-27—Deployment Schedule for Oil Replacement Technologies in the Transportation Sector (oil replacement potential, thousand barrels per day)

Year	Fuel efficiency improvement[a]	Natural gas[b]	Other fuels[c]	Improved traffic management[a]	Total
1991	60	13	5	20	98
1992	120	26	11	40	197
1993	180	39	16	60	295
1994	240	85	21	80	425
1995	300	130	25	100	555

[a] Assumes a uniform deployment over 5 years.

[b] Assumes 30 percent deployment in the first 3 years with the remaning 70 percent deployed during the last 2 years.

[c] Assumes that the excess ethanol capacity replaces 65 percent of the total in the first 3 years, with new plants replacing the remaining 35 percent during the last 2 years.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Table 3-28—Estimated Investment Costs for Oil Replacement Technologies in the Transportation Sector (approximate investment cost in thousand 1990 dollars per barrel per day of oil replaced)

	$ 1,000 per B/D replaced		
Option	Minimum	Maximum	Remarks
Improvement in fuel efficiency	0	0	Assumes that automobile manufacturers shift production towards more efficient cars.[a]
Conversion to natural gas	21	26	1.2 million conversions at $1,500-$2,000 per vehicle plus $988 million for refueling stations to displace 130,000 B/D.[b]
Conversion to other fuels	60	90	Assumes $100-$150 million cost for 50 million gallons/year ethanol plant operating at 85% capacity factor.[c]
Improved traffic management	0	0	Adoption of various measures to promote fuel saving.[a]

[a] Negligible cost.

[b] Vehicle conversion costs in British Columbia were about $1,500 each. Patrick L. McGeer and Enoch J. Durbin, "Natural Gas in Cars—and Step on It," *The New York Times*, Sept. 14, 1990. A conversion cost of $2,000/vehicle based on American Gas Association, *The Outlook for Gas Energy Demand: 1990-2010*, May 1990. Refueling station cost from: U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990), p. 104.

[c] One gallon of ethanol replaces 0.6 gallons of gasoline.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Deployment Considerations and Schedule

The estimated deployment schedule for each of the oil replacement options is shown in table 3-27. The schedule assumes that the gains in fuel savings are evenly spread over the 5-year period.

Possible constraints on achieving these savings have been noted in the text and we have reflected these limitations in our estimates. Sufficient supplies of natural gas for transport needs have been assumed in these estimates. Some of the uncertainties about natural gas availability are discussed later in this chapter.

Estimated investment costs for the various oil replacement options in the transportation sector are shown in table 3-28. The costs of more fuel efficient replacement LDVs have been excluded, because this is a continuing activity. The costs for improved traffic management actions also have been assumed to be minimal because they largely utilize existing mechanisms and infrastructure. This treatment of these costs is consistent with the 1984 analysis. Estimated costs for oil replacement range from about $21,000 to $26,000 B/D for the assumed natural gas vehicle conversions and refueling network network to $60,000 to $90,000 B/D for construction of additional ethanol production capacity.

DOMESTIC PETROLEUM SUPPLY

In 1989 domestic sources supplied about 10.1 MMB/D of petroleum—7.6 MMB/D of crude oil, 1.6 MMB/D of natural gas plant liquids (NGPL), and about 0.9 MMB/D of processing gain.[191] (See figure 3-10.)

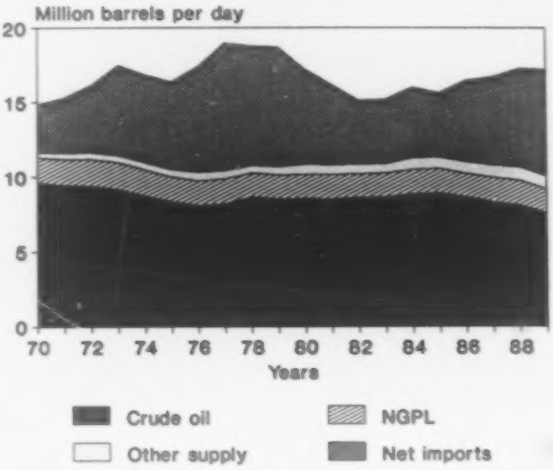
Since 1985, when domestic crude oil production peaked at about 9 MMB/D,[192] production has been declining largely owing to the following factors: a sharp drop in oil prices; reduced drilling activity; abandonment of high-cost, low-volume wells; and impediments to production in environmentally sensitive areas.[193]

In a 1987 study, OTA analyzed these factors and the changes that had taken place in the oil industry. Based on its analysis, we concluded the following:[194]

- Even with optimistic assumptions about the productivity of future drilling, a continuation of 1986 drilling rates would lower production in year 2000 to about 6 MMB/D—a third lower than the 1985 production level—if oil prices remained in the range of $12 to $18/bbl (in 1986 dollars).
- Estimates of the magnitude of the production decline should be viewed as "best guesses" because most forecasts had been based on historical trends and relationships, which might no longer be valid.
- It was not clear whether a break with past trends would lead to higher or lower production levels.

Clearly, the difficulties identified by OTA are further compounded in the present study because there is no historical precedent for the recent sharp drop in oil prices of the last few years and the subsequent possibility of an imported oil cutoff. A continuing decline in domestic production could aggravate any future crisis or policy-driven oil replacement program by offsetting gains from the deployment of oil-saving technologies.

Figure 3-10—U.S. Petroleum Supply, 1970-89



SOURCE: Office of Technology Assessment, 1991, based on data in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 50.

We estimate that with an extension of current trends, domestic oil production could decline to a level of 8.9 to 10 MMB/D by 1995, thus creating an internal shortfall of 0.1 to 1.2 MMB/D on top of an imported oil cutoff of 5 MMB/D under our oil disruption scenario.

Potential Oil Production

Compared to other oil-producing regions, the United States has been extensively explored. Experts estimate that 80 percent of the oil and gas eventually to be found in the United States lies in fields that have already been discovered.[195] The remaining exploratory potential is also substantial. But much of this undiscovered oil and gas will come from smaller fields than in the past.

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[191] *Annual Energy Review 1989*, supra note 6, tables 50 and 51. Processing gain is the amount by which total refinery output volume exceeds the volume of input for a period of time. The gain is created because the refinery process converts crude oil and other hydrocarbons into products that are, on average, less dense than the input.

[192] Ibid.

[193] *National Energy Strategy, Interim Report*, supra note 39.

[194] U.S. Congress, Office of Technology Assessment, *U.S. Oil Production: The Effect of Low Oil Prices-Special Report*, OTA-E-348 (Washington, DC: U.S. Government Printing Office, September 1987), pp. 1-2.

[195] W.L. Fisher, "Factors in Realizing Future Supply Potential of Domestic Oil and Natural Gas," paper presented to the Aspen Institute Energy Policy Forum, July 10-14, 1991, Aspen Colorado.

This maturity does not mean that the future for the U.S. oil industry is a rapid and inevitable decline in production from increasingly high-cost deposits. Many in the oil industry hold to a belief that domestic production can be stabilized or slightly increased. In support they note the continuing strength in U.S. reserves additions and a more sophisticated understanding of the nature of U.S. oil and gas resources.

Even as drilling activity has slowed, reserve additions since 1986 have averaged 90 percent of those in the high oil price-high activity years 1978 to 1985. An estimated 86 percent of these reserve additions are attributable to reserve growth in existing fields—that is, increases in the estimates of conventionally recoverable oil resulting from extensive and intensive drilling within existing fields, improved recovery, and identification of new pools.[196]

The past decade has brought recognition that sizable quantities of conventionally mobile oil remain to be recovered in existing fields. The greatest potential recovery is contained in complex reservoirs that will require improved geologic models to make infill drilling and enhanced oil recovery more effective in tapping these deposits. Evolving enhanced oil recovery techniques eventually could allow production of the immobile, residual oil in existing reservoirs.

Tapping these resources is contingent on the economic attractiveness of the prospects at present and anticipated world oil prices, and continued technology development. The higher oil prices and sense of urgency accompanying a severe oil import disruption would likely provide some impetus for expanded exploration and development.

In September 1990 a leading petroleum industry trade magazine, *Oil & Gas Journal* (O&GJ), estimated that 1990 domestic crude oil production would be about 7.2 MMB/D,[197] or a decline of about 5.3 percent from the 1989 production of 7.6 MMB/D. Preliminary estimates peg actual 1990 U.S. crude oil output at 7.4 MMB/D, a decline of about 3.4 percent.[198] The higher than expected production levels have been attributed to the higher world oil prices after the Iraqi invasion of Kuwait, and expanded production in Alaskan oil fields following completion of North Slope maintenance projects.

The higher oil prices in 1990 also brought about a brief upswing in exploration indicators, but by late spring 1991, these critical indicators were again trending downward as lower world oil prices returned and domestic natural gas prices all but collapsed.[199] Even so, for the first time since 1985 domestic crude oil production increased in 1991—up 0.6 percent over the first six months of 1990. The rise was attributed to better economic conditions for producers, the expanded exploration and development activities in 1990, and improved technology.[200] This brief surge in investment and drilling activity reaffirms the expectation that higher prices accompanying a severe oil import disruption could boost the exploration and production of domestic crude oil.

Potential opportunities for increased domestic production rest with the discovery of new fields in frontier areas and with improving oil recovery in existing fields. Over the 5-year horizon of our oil replacement scenario, incremental production from existing fields is the most promising option. However, available data are neither consistent nor reliable for estimating potential production increases and, most particularly, for predicting the natural decline in production. Moreover, it is not clear that available technologies and resources could slow the natural decline over the next 5 years stemming from the low levels of drilling activity over the past 5 years.

Production from new, large reservoirs is excluded from our assessment because there are no near-term prospects. Even if the coastal plain areas of Alaska's Arctic National Wildlife Refuge (ANWR) and the most promising offshore frontier areas were to be made available for exploration and development today, production could not start until after the year 2000.[201]

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[196] Ibid.

[197] "Despite Output Push, U.S. Probably Cannot Avoid Oil Production Decline in 1991", *Oil & Gas Journal*, vol. 88, Sept. 17, 1990, page 21.

[198] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review: July 1991*, DOE/EIA-0035(91/07) (Washington, DC: U.S. Government Printing Office, July 1991), table 3.2a.

[199] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review: June 1991*, DOE/EIA-0035(91/06) (Washington, DC: U.S. Government Printing Office, June 1991) and Institute of Gas Technology, *International Gas Technology Highlights*, vol. 21, July 15, 1991.

[200] See "Oil Demand Falls to Lowest Level Since 1983," *The Energy Daily*, Jul. 18, 1991, p. 4.

The 1990 O&GJ review concluded that under an optimistic price scenario, using the best efforts of U.S. producers, existing fields could be expected to provide an additional 374,000 B/D within 1 year. However, O&GJ then proceeds to subtract a hefty natural decline of 5 percent, an amount comparable to the 1989-90 decline, thus concluding that the actual net increase by the end of 1991 would be negligible.[202] Since past natural decline rates reflect the strong impact of low oil prices on production and new drilling activities,[203] this rationale would not be valid during a crisis scenario.

We have taken a different approach for estimating potential production gains. Using the data below on potential opportunities identified by O&GJ, we reviewed the prospects for achieving their production capability over a 5-year period in light of known constraints. We address the issue of natural decline separately.

The major potential opportunities identified by O&GJ are as follows:[204]

- Bringing back some 75 percent or about 100,000 B/D of the 150,000 B/D of (mostly heavy) oil production in California lost since 1985,
- Bringing on line new production from offshore fields in California to add 140,000 B/D from the Santa Barbara Channel, 75,000 B/D from the Point Arguello field, and 65,000 B/D from the Santa Ynez Unit.
- Increasing production from existing Alaskan fields by about 200,000 B/D, or almost 11 percent over its 1989 production.
- Increasing the combined production in the Gulf Coast, Mid-continent, Midwest, and Rocky Mountain regions by about 70,000 B/D.

Constraints to Production

There are several constraints that could reduce this potential. In 1988, enhanced oil recovery (EOR) supplied about 640,000 B/D. Of this supply, thermal EOR had an 80 percent market share, or about 510,000 B/D.[205] The majority of the thermal EOR projects are in California. Any increase in the deployment of thermal EOR projects would have to overcome strict environmental constraints. For example, currently in California, if an existing steam generator is relocated, the new permit reduces the allowable environmental offsets by a factor of 2 to 5.[206] These regulations could limit the flexibility of a producer to shift production from one field to another. Moreover, any new EOR projects would require an increased supply of coal or natural gas. It is not clear whether increased use of coal would be allowed in California, even if coal technologies could meet environmental limitations.

With respect to increasing the natural gas supply, there is a jurisdictional dispute between the California Public Utility Commission and the FERC.[207] Any delay in resolving this dispute in the courts could result in a delay of new pipeline projects aimed at bringing additional natural gas to California. As of August 1991, most of the pending disagreements had been resolved.

Even if environmental permits could be obtained in 1 or 2 years, typically an additional 1-year period would be necessary to achieve breakthrough in California's heavy crude oil fields.[208] Thus, any delays in the permitting process would further reduce the prospects for incremental production in California. We have assumed a range of 0 to 100,000 B/D for California's onshore incremental production over 5 years.

The $2 billion Point Arguello project in the Santa Barbara Channel off California has been lying idle for the last 3 years because of debate over the initial mode of transportation to market—tankers v. existing pipeline.[209] It is not clear when the dispute between Santa Barbara County and the California Coastal Commission and the project sponsors, led by Chevron, will be resolved to permit the projected flow of 75,000 B/D from the mothballed project. In the meantime Chevron announced that it is planning to begin production of about 20,000 B/D from Point Arguello.[210]

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[201] Ibid. John H. Gibbons, Director, U.S. Congress, Office of Technology Assessment, "On Relieving U.S. Oil Dependence," testimony before the Senate Committee on Energy and Natural Resources, Oct. 2, 1990.

[202] *Oil & Gas Journal,* supra note 197.

[203] Robert Williams, *Oil & Gas Journal,* personal communication to Renova Engineering, P.C., OTA contractor, Oct. 26, 1990.

[204] *Oil & Gas Journal,* supra note 197.

[205] Robert Williams, personal communication, supra note 203.

[206] Raymond L. Schmidt, Chevron Oil Research Company, personal communication to Renova Engineering, P.C., OTA contractor, Oct. 25, 1990.

[207] New Pipeline Construction Projects-Status Report, American Gas Association, Issue Brief 1990-5, Apr. 13, 1990.

[208] Raymond L. Schmidt, personal communication, supra note 206.

The proposed expansion by Exxon of its Santa Ynez project, also in the Santa Barbara Channel, is projected to supply an additional 65,000 B/D by 1994-95.[211] Any delays in its environmental permitting process would extend this production date.

Thus, only under an optimistic scenario could California's offshore production be increased by the full 140,000 B/D over the next 5 years. A more likely projection would be a range of 70,000 to 140,000 B/D.

Production from Alaska's Prudhoe Bay is already declining. Some of Alaska's other fields could go into production over the short term because they were idled for economic reasons. DOE estimates that a resolution of permitting problems could result in a production of up to 100,000 B/D from two developed fields, Niakuk and Point McIntyre, in the Beaufort Sea.[212] On the other hand, given technical and environmental constraints, it is not clear that marginal fields in Alaska could reach full commercial production in 5 years. We have assumed a range of 100,000-200,000 B/D for incremental production from Alaska.[213]

Geologically targeted infill drilling (GTID), or horizontal drilling, could be used to produce unrecovered mobile oil that is not amenable to conventional primary and secondary techniques.[214] A combination of GTID, polymer-augmented water flooding, and permeability profile modification could be deployed to increase production in the 48 contiguous States. For example, based on an analysis of a limited resource base in Texas, Oklahoma, and New Mexico, it is estimated that a price of $20/barrel could justify the recovery of over 1 billion barrels using a combination of infill drilling and waterflood methods. Such a program would require drilling about 26,000 new wells at one-half of current spacing.[215]

The number of drilling rigs in operation has declined from a peak of 3,970 in 1981 to 869 in 1989.[216] The 1990 count is expected to rise to about 1,000. In some areas, this turnaround has already created a shortage of competent people necessary for operating the rigs.[217] With intensified training programs some of the mothballed rigs could be redeployed in a crisis. However, it is not clear whether the intensive drilling entailed in a GTID program could add any significant amount of production in 5 years. Moreover, although independent producers drill the vast majority of wells, and supply about 40 percent of the Nation's needs, many of them probably lack the resources for intensifying the geological studies that are essential for GTID.[218]

Increased carbon dioxide (CO_2) flooding projects, while feasible, are probably limited by cost considerations to those companies that have a captive access to CO_2.[219] Research projects are under way to improve the economics of EOR using chemical flooding, as, for example, using lignin-based chemicals. The new processes are not commercially proven.[220]

As a result, we estimate that Gulf Coast, Midcontinent, Midwest, and Rocky Mountain regions would face serious constraints in achieving a combined production increase of about 70,000 B/D. Rather, we believe that 70,000 B/D would be at the high end of a range that could be as low as zero.

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[209] *Oil & Gas Journal,* supra note 197.

[210] Thomas C. Hayes, "Breaking Logjam on California Oil," The New York Times, Nov. 29, 1990.

[211] *Oil & Gas Journal,* supra note 197.

[212] "DOE Plans to Help Boost U.S. Oil Production," *Oil & Gas Journal,* vol. 88, Sept. 24, 1990, page 52.

[213] "U.S. Oil Flow Hike Unlikely Outside W.Coast," *Oil & Gas Journal,* vol. 88, Oct. 15, 1990, page 32.

[214] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?, Vol. 2, Pt 2 of 3, Supply Technology,* ORNL-6541/V2/P2 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1989) pp. 10-15.

[215] A.B. Becker, J.P. Brashear, K. Biglarbigi and R.M. Ray, "Evaluation of Unrecovered Mobile Oil in Texas, Oklahoma, and New Mexico," paper presented at the SPE/DOE Seventh Symposium on Enhanced Oil Recovery, Tulsa, Oklahoma, Apr. 22-25, 1990.

[216] *Annual Energy Review 1989,* supra note 6, table 41.

[217] Guntis Moritis, "Drilling Continues Upward Momentum," *Oil & Gas Journal,* vol. 88, Sept. 24, 1990, page 65.

[218] Raymond L. Schmidt, personal communication, supra note 206.

[219] Bobby Hall, American Petroleum Institute, personal communication to Renova Engineering, P.C., OTA contractor, Oct. 23, 1990.

[220] Janice R. Long, "More Energy Research Called for to Stem Oil, Climate Change Crisis," *Chemical & Engineering News,* Sept. 10, 1990, p. 16.

Natural Decline

Characteristically, there is a natural decline in output from existing production fields as the reserve is exhausted. There are technical means to slow the rate of decline, but depletion is inevitable.[221] At an assumed rate of about 1.0 percent per year, the 1995 domestic oil production would be in the range of 6.8 MMB/D, for a total natural decline of about 400,000 B/D compared with the 1990 production. At a rate of 3 percent per year, the production would be about 6.2 MMB/D for a decline of about 1 MMB/D.

Incremental Production of NGPL

In 1989 the Nation produced about 17.3 TCF of natural gas and 1.6 MMB/D of NGPL.[222] A similar production level was assumed for 1990. At a heat content of 3.8 MM Btu/bbl for NGPL[223] and 1,000 Btu/ft^3 for natural gas, the NGPL production was about 13 percent of the natural gas production. Assuming that during a crisis, the natural gas production could be increased by 1 to 2 TCF over a 5-year period, an additional supply of 0.13 to 0.26 quads of NGPL, or about 100,000 to 200,000 B/D of NGPL could be realized.

Estimated 1995 Domestic Petroleum Supply

We estimate, therefore, that by 1995, the Nation's domestic petroleum supply would more likely be in the range of about 8.9 to 10.0 MMB/D, as shown in table 3-29. At this level, the domestic supply would create an additional shortfall of 0.1 to 1.2 MMB/D, as compared with the 1989 supply of 10.1 MMB/D.

Table 3-29—Estimated 1995 Domestic Petroleum Supply (million barrels per day)

Source	1990	1991-95
Crude oil production		
Current level[a]	7.20	
Incremental crude oil production		
New fields		0.00 - 0.00
Existing fields		
California (onshore)		0.00 - 0.10
California (offshore)		0.07 - 0.14
Alaska		0.10 - 0.20
Other Lower 48 States		0.00 - 0.07
Subtotal incremental production		0.17 - 0.51
(Offset for projected production decline)		(1.00)-(0.40)
NGPL production		
Current level[b]	1.60	
Incremental NGPL supply		0.10 - 0.20
Processing gain[c]		0.81 - 0.91
Total 1995 domestic supply		8.88 -10.02

[a] "Despite Output Push, U.S. Probably Cannot Avoid Oil Production Decline in 1991," *Oil & Gas Journal*, vol. 88, Sept. 17, 1990, p. 21. Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference*, vol. 2, Part 1 of 3, End-Use Technology, ORNL-6541/V2/P1 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1989), p. 5.

[b] Assumed at the 1989 level based on data reported in U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC: U.S. Government Printing Office, May 1990), table 62.

[c] Ibid., prorated from 1989 data which indicates that the processing gain amounts to about 10% of the crude oil and NGPL supplies.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

Investment Cost

In an earlier report, it was estimated that solid fuel-fired steam flooding EOR projects would require an investment of $10,000 to $20,000 per B/D.[224] The cost for CO_2 flooding was estimated to be $20,000 to $40,000 per B/D.[225] A 50-percent escalation of these 1982 costs would indicate that the 1990 costs would be in the range of $15,000 to $60,000 per B/D.

OTHER FACTORS AFFECTING OIL REPLACEMENT POTENTIAL

By deploying various short-term oil replacement technologies, OTA believes that it is technically feasible to displace about 2.9 MMB/D of petroleum products at the end of the 5-year period between 1991 and 1995. Table 3-30 and figure 3-11 summarize the oil replacement potential that could be achieved in each sector. Natural gas, coal, and electricity could displace about 1.8 MMB/D of the total. See figure 3-12. Renewable fuels, nuclear, and other options such as fuel efficiency improvement, industrial process changes, and improved traffic management could displace about 0.7 MMB/D. Finally, an additional 0.36 MMB/D could be saved by reduced refinery throughput.

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[221] Thomas C. Hayes, supra note 210.

[222] *Annual Energy Review 1989*, supra note 6, tables 50 and 51.

[223] U.S. Department of Energy, Energy Information Admininstration, *Monthly Energy Review: April 1990*, DOE/EIA-0035(90/04) (Washington DC: U.S. Government Printing Office, July 1990.

[224] Gibbs & Hill, Inc., supra note 5.

[225] *Monthly Energy Review: April 1990*, supra note 223.

These potential oil savings must, however, be offset by the likely continuing decline in the domestic petroleum supply, even with the advent of higher prices stemming from a shortage of oil imports that could spur additional drilling. The magnitude of this decline cannot be projected with any certainty. We estimate it to be in the range of 0.1 to 1.2 MMB/D below 1989 production by 1995. The net result is that, of the 5 MMB/D of imported oil lost in a crisis, only about 1.7 to 2.8 MMB/D can be replaced by energy technologies.

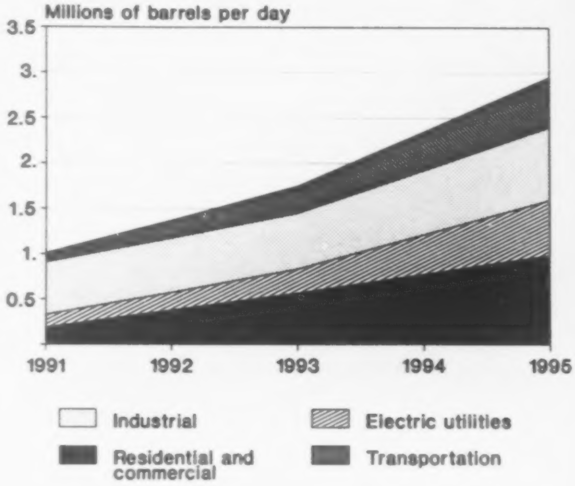
The total investment needs during a crisis will depend on policy, regulatory, and economic decisions adopted by the Nation to spur the deployment of technologies. For illustration purposes only, we have summarized in table 3-31 a breakdown of the estimated capital requirements for deploying all of the technologies identified in this analysis. Using the average of the range of costs for each technology, the investment needs would be about $140 billion. The range is estimated to be $70 to $210 billion.

Uncertainties in Achieving Technical Replacement Potential

For purposes of this analysis, we have assumed that legislative and policy initiatives to promote the use of oil replacement technologies are adopted promptly after the onset of the crisis. We have also assumed that adequate capital is made available to finance the manufacture, purchase, and installation of the needed equipment. Uncertainties remain about the availability of four critical resources: natural gas, electricity, refinery capacity, and technical personnel.

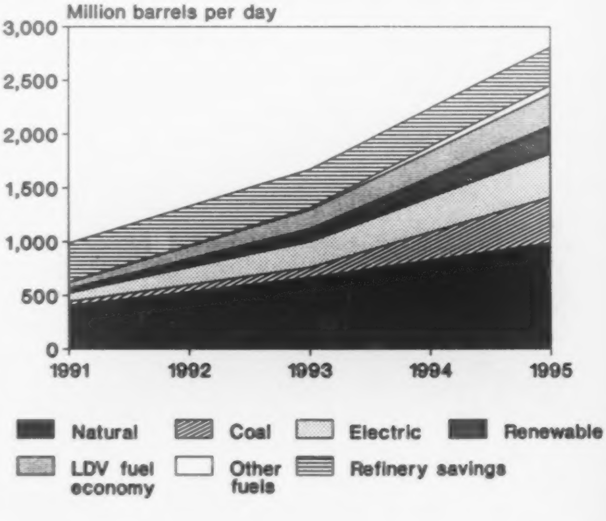
Our review concluded that the supplies of natural gas and electricity are not likely to raise substantial impediments to full deployment of oil replacement technologies at present. However, the availability of

Figure 3-11—U.S. Technical Capability To Replace Lost Imports in an Oil Supply Disruption, 5-Year Deployment Schedule by Sector



SOURCE: Office of Technology Assessment, 1991.

Figure 3-12—U.S. Technical Capability To Replace Lost Imports in an Oil Supply Disruption, Replacement Potential by Source



SOURCE: Office of Technology Assessment, 1991.

Table 3-30—Summary of Estimated Oil Replacement Potential
(thousand barrels per day)

Petroleum products replaced	Natural gas	Coal	Electricity	Renewable fuels	Nuclear	Other	Total
Electric utility residual oil[a]	85	360	NA	95	44	15	599
Residential/commercial							
Distillate oil and kerosene	440	7	215	23	NA	22	
Residual oil	NA	39	NA	b	NA	b	
LPG	38	16	192	b	NA	b	
Subtotal	478	62	407	23	NA	22	992
Industrial							
Crude oil[c]	NA	NA	NA	NA	NA	360	
Distillate and	232	17	16	17	NA	100	
residual oil	NA	d	d	d	NA	NA	
LPG & other products	65	NA	NA	NA	NA	e	
Subtotal	297	17	16	17		460	807
Transportation							
Gasoline and diesel	130	NA	NA	25	NA	400[f]	555
Total replacement potential: end-use sectors	990	439	423	160	44	897	2,953
Offset for expected domestic petroleum production[g]							(100)-(1,200)
Total net replacement potential							1,700-2,800

NA = not applicable

[a] Other non-fuel option is demand management.

[b] Renewable fuels and efficiency improvement options replace a total of 45,000 B/D of petroleum products in the residential commercial sectors.

[c] Savings resulting from reduced refinery throughput.

[d] Coal, electricity and renewable fuels replace a total of 50,000 B/D of distillate and residual oil in the industrial sector.

[e] Process changes replace a total of 100,000 B/D of products.

[f] Includes fuel efficiency improvement which saves 300,000 B/D, and improved traffic efficiency management which saves 100,000 B/D.

[g] Difference between the 1989 supply and the potential supply in 1995. (See table 3-29.)

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

adequate refinery capacity and trained technical and craft workers could be of concern. These subjects warrant a more detailed study of their full impacts.

Natural Gas Supplies

Switching to natural gas could displace about 1 MMB/D of petroleum products. We estimate (based on an average heat content of 5.5 million Btu/bbl for the products displaced) that this switching could increase the annual natural gas consumption in 1995 by about 2 quads—10 percent more than the 1989 consumption of about 19.4 quads. Domestic natural gas production was about 17.7 TCF in 1989, and imports were about 1.4 TCF.[226] For much of the 1980s, there was a surplus of natural gas production capacity that kept prices down. Various estimates have placed the size of the gas "bubble" at 2 TCF or more, and gas reserve additions have been growing. Most industry analysts project that U.S. gas producers could match increased demand rather quickly. The American Gas Association (AGA) has forecasted that under a high-price scenario, the industry could supply about 19.9 TCF in 1995.[227] AGA's

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[226] *Annual Energy Review 1989*, supra note 6, table 71

[227] American Gas Association, "The Gas Energy Supply Outlook 1989-2010," September 1989..

Table 3-31—Summary of Estimated Investment Costs for Oil Replacement Technologies

Sector	Natural gas	Coal	Electricity	Renewable fuels	Nuclear	Other	Total
	($1,000 per B/D of petroleum products replaced[a])						
Electric utility	17	43	—	166	7	99	
Residential and commercial	155	556	71	—	—	163	
Industrial	3	65[b]	[b]	[b]	—	10[c]	
Transportation	24	—	—	75	—	—	
	$ billion (1990)						
Electric utility	1.4	15.6	—	15.8	0.3	1.5	34.6
Residential and commercial	26.4	34.5	28.7	—	—	7.2	96.7
Industrial	0.7	3.3	—	—	—	1.0	5.0
Transportation	3.1	—	—	1.9	—	—	4.9
Total replacement	31.7	53.4	28.7	17.7	0.3	9.6	141.3
Domestic oil production[d]							5.0
Total							146.3

[a] An average of the amounts for individual replacement options for each end-use sector.

[b] Coal, electricity and renewable fuels replace a total of 50,000 B/D of distillate and residual oil in the industrial sector. Assumes that average cost is equivalent to that for coal.

[c] Excludes the reduced refinery throughput because of oil shortfall.

[d] Assumes 100,000 B/D from enhanced oil recovery at $50,000/B/D.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

high-price scenario assumed a 1995 oil price of $30/bbl (1988 dollars). By contrast, the low-price scenario of oil at $18/bbl forecasted a supply of about 17 TCF. Natural gas prices were not driven up following the invasion of Kuwait in August 1990, in large part because of the ample supplies of natural gas available.

For some regions the pipeline capacity to deliver natural gas and the storage capability are the critical constraints on natural gas availability. At present, in winter months, utility and industrial customers switch from gas to oil because of deliverability constraints. Switching these customers as well as new residential customers to gas could be hindered if local gas deliverability and storage capability are limited. Several pipeline projects, currently under various stages of development across the country, would improve gas availability, even in the absence of a crisis.[228] In particular, several projects are aimed at bringing domestic and Canadian gas to the Northeast and California. The projects in the Northeast are driven by industrial, utility, and independent power demand, while those in California are driven by the demand in EOR applications. Assuming that these pipelines receive the necessary license and permit approvals, the supply of natural gas should not be a constraint to oil replacement on either a national or regional scale.

Electricity

Oil-based electric generation capacity is concentrated in the Northeast, Florida, and California. New England and the Middle Atlantic States also depend on oil for residential heating. The combined impacts of backing out utility oil use and at the same time converting a sizable number of residential heating

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[228] American Gas Association, "New Pipeline Projects—Status Report," Issue Brief 1990-5, Apr. 13, 1990.

Table 3-32—Summer Electricity Supply Data for Oil-Dependent NERC Regions (MW)

	Projected capacity and additions				
NERC Region[a]	Installed capacity 1989[b]	Installed capacity 1995[b]	Total capacity additions 1990 - 95[c]	NUG capacity additions 1990 - 95[d]	Demand management 1990 - 2000[e]
NPCC	54,622	63,151	8,259	5,791	3,850
WSCC	129,533	131,472	5,834	3,409	NR
CNV	53,921	58,317	4,191	2,484	300
SERC	143,325	162,418	17,215	4,181	NR
Florida	30,857	34,352	2,882	1,097	NR
MAAC	49,829	57,092	7,213	3,491	NR

[a] North American Electric Reliability Council (NERC) Regions and Subregions with large oil-based generating capacity—
- NPCC : Notheast Power Coordinating Council, includes New England States and New York.
- WSCC : Western Systems Coordinating Council, includes Northwest Pool (northern California) and CNV (California-southern Nevada) among others.
- SERC : Southeastern Electric Reliability Council, includes Florida.
- MAAC : Mid-Atlantic Area Council, includes New Jersey, Delaware, Maryland, Washington DC, Virginia, and eastern Pennsylvania.

[b] North American Electric Reliability Council, *1990 Electricity Supply & Demand for 1990-1999* (Princeton, NJ: North American Electric Reliability Council, November 1990), table 11.

[c] Ibid., table 28.

[d] Ibid., table 30.

[e] North American Electric Reliability Council, *1990 Reliability Assessment* (Princeton, NJ: North American Electric Reliability Council, September 1990).

NR = Not reported.

SOURCE: Office of Technology Assessment, 1991, from Renova Engineering, P.C., "Oil Replacement Analysis—Evaluation of Technologies," OTA contractor report, February 1991.

systems from oil to electricity could possibly strain available electricity-generating capability in these regions. If the impact were significant, reduced electricity-generating capacity margins could be a limiting factor to achieving full oil displacement potential.

Table 3-32 shows the summer electricity supply data for the relevant NERC regions, including projections for 1990 through 1995. Based on this assessment, the supply of electricity on a regional basis should not be a limiting factor because utilities in these regions have readily available capacity and technological options to reduce their dependence on oil. Recent developments that have aided utility flexibility in responding to potential oil disruptions include the following:

- Newly added utility and NUG capacity has increased capacity margins and enhanced the potential for contract purchases of non-oil based capacity from other utilities and NUGs to meet new demand.
- Demand management programs have already successfully deferred the need for new capacity and could be accelerated to reduce the impacts of an oil supply crisis.
- New and planned transmission system upgrades are improving capability for interregional transfers of non-oil based electricity. For example, the Mid-Atlantic Area Council plans to strengthen interconnections between utilities in the western part of Pennsylvania and in the Baltimore-Washington area. Similarly, several projects are being developed by the Northwest power pool to bring electricity from the northwestern parts of the United States and Canada to California.[229]
- Planned imports of Canadian power are another alternative that might be accelerated to meet a crisis. For example, New York plans to import an additional 500 MW from Hydro Quebec beginning in the summer of 1995.

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[229] North American Electric Reliability Council, *1990 Reliability Assessment* (Princeton, NJ: North American Electric Reliability Council, September 1990).

Refinery Capability and the Availability of Residual Fuel Oil

In 1989, about 610,000 B/D of residual oil were imported, about 45 percent of total residual consumption. During the 1980s, production of residual fuel oil by U.S. refineries decreased as demand declined and refineries upgraded their capabilities to handle a wider range of crudes and to produce more light products.

Our analysis found that backing out most oil use in the electric utility sector could displace almost all of the residual fuel oil imports in 1989. Although this offers oil savings, it is not at all clear that cutting residual fuel use in a crisis by over 600,000 B/D would free up oil for other uses or allow the residual oil to be processed into lighter products. First, uses of residual fuel oil are already fairly limited. Second, an import shortfall may not translate into a shortage of residual fuel oil. Domestic refiners would continue to produce residual fuel oil as a remnant of the refining process, and only a portion of the residual fuel imports would likely be lost in a crisis. The output of residual fuel by U.S. refineries is dependent on the quality of the crude oil input and the capability of the individual refineries. Simple refineries, which lack cracking capacity, yield a higher portion of residual fuel than do complex and very complex refineries, which have thermal and catalytic crackers and other downstream processing capabilities. In the 1980s, as the portion of input by heavy oils to U.S. refineries grew, many simple refineries shut down, and refinery capacity came to be dominated by the larger, and more flexible, complex and very complex refineries.[230] Several industry observers have suggested that an increase in domestic refining of heavy oils during a crisis might actually result in a surplus of residual fuel oil.

Between 1980 and 1989, the domestic production of residual oil has declined from a level of about 4.4 percent to 2.2 percent of the refinery output.[231] A more detailed study is necessary to evaluate the actual capability of U.S. refineries to produce products of higher value from residual oil as well as the potential for increased transfer of excess refinery products to friendly countries during a crisis.

Technical Personnel

Many of the oil replacement technologies are highly capital-intensive and require very specialized technical skills. Several oil replacement options involve construction projects for implementing energy technologies. In addition to EOR, the major options requiring construction are those related to the use of coal and renewable fuels in electric utilities, commercial buildings, and industries.

We estimate that such construction projects would require about $75 billion. Services typically account for around 40 percent of the cost of such projects, the balance being for material and equipment. Of the amount allocated for services, engineering and construction management (E/CM) would use about 25 percent, with construction craft labor using the remaining 75 percent. Typically, most of the expenditure on services would be incurred over a 2-year period.[232]

On this basis, E/CM services would amount to about $4 billion per year and field construction craft labor to about $13 billion. Based on $125,000 and $60,000 per person per year for E/CM and craft labor, respectively, the incremental manpower needs would be 32,000 E/CM personnel and 375,000 craft labor.

In 1983, the E/CM and heavy construction craft labor pools were estimated to be about 0.1 and 1 million, respectively. Accordingly, we believe that this demand could strain the existing pool of skilled professional and craft workers and possibly create delays in deploying the technologies. Our oil replacement estimates have assumed that labor shortages do not constrain deployment of fuel-saving technologies. More study would be necessary to assess the personnel availability limitations, taking into account such issues as use of modular and standardized designs, intensified retraining programs, and the impact of an economic slowdown brought on by an oil crisis.

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[230] U.S. Department of Energy, Energy Information Administration, *The U.S. Petroleum Refining Industry in the 1980's*, DOE/EIA-0536 (Washington, DC: U.S. Government Printing Office, October 1990).

[231] *Annual Energy Review 1989*, supra note 6, tables 57 and 60.

[232] Gibbs & Hill, Inc., supra note 5.

Chapter 4

Economic Aspects of Oil Replacement Strategies

Contents

Page

INTRODUCTION 105

ECONOMIC IMPACTS OF OIL SUPPLY DISRUPTIONS 106

- Why Estimates Vary 106
- Two Measures of Economic Impacts 106
- OTA's 1984 Analysis of Responses to a Severe Oil Import Curtailment 106
- Differences Between the 1984 and the 1991 Assessments 107
- Analysis of the Economic Impacts of an Oil Replacement Strategy, 1991 108
- Further Research 111

CONCLUSION 112

Tables

Table *Page*

- 4-1 Disruption Size and Oil Price Impacts, MMB/D and Prices in 1990 $/barrel 110
- 4-2 Comparison of U.S. Economic Impacts of a Sustained Oil Disruption and an Oil Replacement Strategy 111

Chapter 4
Economic Aspects of Oil Replacement Strategies

INTRODUCTION

Past oil shocks have had severe impacts on the economy, contributing to inflationary pressures and causing widespread unemployment.[1] During the 1970s, the growth rates of the seven major Organization for Economic Cooperation and Development (OECD) countries were cut in half by higher oil, raw material, and food prices and the policy responses to those shocks. In the mid-1980s, Stanford University's Energy Modeling Forum[2] concluded that a sustained oil price shock comparable in size to those experienced during the 1970s would cost $2,000 per U.S. resident when the costs are cumulated over a 4-year period.[3] More recently, some analysts have attributed the recent slowdown in economic activity, at least partly, to the price jump in August through October as tensions mounted in the Persian Gulf over Iraq's invasion of Kuwait, even though these price increases were only temporary.

This chapter discusses the likely economic impacts of a major oil disruption in which all of the 16 million barrels per day (MMB/D) of Persian Gulf oil is removed for 5 years. These effects are compared with a baseline scenario depicting stable oil market conditions. The analysis incorporates price-driven replacement of oil but without additional policy initiatives. A second scenario considers the effect of such a disruption when the Nation simultaneously accelerates the use of oil replacement technologies discussed in chapter 3. The analysis addresses three central issues: 1) the effect of a major disruption on oil prices, 2) the effects of these oil price changes on the U.S. economy, and 3) the effect of an aggressive U.S. oil-replacement policy on mitigating the oil price shock during a major disruption.

Impacts on the prices and on the economy are derived for two time periods—2 years and 5 years after the disruption. Economic impacts are measured in terms of changes in real gross national product (GNP), which is a measure of the Nation's total production of goods and services. In addition, the chapter also reports separate estimates of changes in real national income, which is a broader economic indicator that measures the country's ability to purchase goods and services on the international market. Changes in real national income incorporate both changes in physical production of goods and services and changes in the purchasing power of income received for producing those goods and services.

The analysis reveals four key conclusions:

1. The U.S. economy has achieved significant improvements in oil efficiency over the years. Coupled with today's lower oil prices, this situation has made the U.S. economy less vulnerable to sudden oil price shocks than during much of the 1970s and 1980s.
2. The world economy has become more dependent on oil supplies from the Persian Gulf. This trend increases the economic damage that can result from losing oil supplies from this politically volatile region.
3. The merits of an accelerated oil replacement strategy depend on how the policy is implemented. The strategy will be most effective when it targets least costly options and when it is matched by policies in other countries. It will be least effective when it targets unproven options that turn out to be expensive and when it is adopted unilaterally by one country.
4. Future research in this area should focus on the costs of different technology options as well as the potential for replacing oil use. Two policies replacing the same amount of oil can have very different economic impacts if the incurred costs are dissimilar.

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[1] See, e.g., those studies reviewed by R.S. Dohner, "Energy Prices, Economic Activity, and Inflation: A Survey of Issues and Results," in K.R. Mork, *Energy Prices, Inflation, and Economic Activity* (Cambridge, MA: Ballinger, 1981). For a contrarian view, see Douglas R. Bohi, *Energy Price Shocks and Macroeconomic Performance* (Washington, DC: Resources for the Future, 1989).

[2] The Energy Modeling Forum conducts studies to improve the usefulness of energy models for understanding important energy problems. Each study is conducted by an ad hoc working group of about 40 individuals from government, business, and universities.

[3] These costs are the undiscounted sum of 4-year losses measured in 1983 dollars. They represent about 12 percent of total GNP for the year, 1983. See also, Energy Modeling Fourm, *World Oil;* EMF Report 6 (Stanford, CA: Stanford University, 1982); and Energy Modeling Forum, *Macroeconomic Impact of Energy Shocks;* EMF Report 7 (Stanford, CA: Stanford University, 1985).

ECONOMIC IMPACTS OF OIL SUPPLY DISRUPTIONS

Oil disruptions contribute to inflationary pressures and create widespread unemployment. These hardships emerge in all economies that rely heavily on oil. It makes little difference whether a country is an exporter or importer of oil; both types of economies have suffered about qually, accounting for other factors.

Why Estimates Vary

While there is general agreement that oil disruptions create economic hardships, there is less agreement about the magnitude of these impacts because a number of factors contribute to how high prices rise and how much economic growth is affected.

The removal of oil supplies from an integrated market will cause prices to rise in order to constrain demand and encourage additional supplies from regions not curtailed by the interruption. One important determinant of how high prices will move is the relative importance of the disruption to total world oil supplies. Another is the responsiveness of oil supplies and demands to price. In addition, the expectations of market participants can be extremely important. During past oil shocks, anticipatory behavior and inventory policies have caused prices to rise substantially, even when the physical volumes removed have been relatively small. It is extremely difficult to evaluate how expectations affect oil prices quantitatively.

Once the oil price increase is known, the size of the economic impacts will depend on a number of factors: the baseline economic conditions before the shock, the stickiness in wages and prices throughout the economy, the policies used to offset either the inflationary pressures or growing unemployment, and the relative importance of oil in economic activity. Moreover, expectations about how the economy adjusts and how policymakers will respond can have an important effect on the ultimate economic impacts.

Two Measures of Economic Impacts

There are many possible measures of the economic impacts of oil price shocks. This chapter reports results for changes in real GNP and for changes in real national income. The major effects causing each impact are discussed briefly below.

Changes in Real GNP

Higher oil prices reduce aggregate economic output in both the short and long run. In the near term, total spending falls, causing the economy to experience widespread unemployment. A key culprit in this process is the stickiness in other prices and wages that prevents price declines for most goods and services. As a result, the oil price shock temporarily causes the economy's general price level to rise more. This development will push interest rates higher, particularly if policymakers fear renewed inflation and hold the money supply unchanged (or even reduce it). Higher interest rates curtail first investments and then additional spending associated with those direct investments through the multiplier effect. Domestic spending may also be lessened as higher prices reduce real wealth and purchasing power. Ultimately, as prices and wages adjust to the higher oil prices, the economy moves back closer to its full employment level. Over the longer run, a sustained oil price increase will cause the productivity of labor and capital to decline because the substitution for oil leaves existing labor and capital with less energy to work with.

Changes in Real National Income

Higher oil prices also harm the economy in another way. Even if total physical production is not changed, the distribution of that output between foreigners and domestic residents is altered. The economy must now allocate more wheat and other exports for paying for oil imports and retain less of these goods for domestic consumption. The Nation's purchasing power over all goods purchased (including imported oil) is reduced by the higher cost of oil. Owing to the conventions of national income accounting, this reduction in real national income is not incorporated by the change in real GNP measured by macroeconomic models.

OTA's 1984 Analysis of Responses to a Severe Oil Import Curtailment

In the 1984 study, a world oil supply shortfall of 9 to 10 million barrels per day (MMB/D) over a 5-year period was assumed to result in a 3 MMB/D reduction in oil available in the United States.[4] Nevertheless, U.S. technical oil replacement potential was deemed great enough to replace 3.6 MMB/D of the expected 3 MMB/D decline within a 5-year period.

It was realized, however, that the technical potential might not result in actual reductions if price conditions or policies did not motivate individual decisionmakers to make the requisite capital investments and behavioral adjustments. Thus, two response cases were considered: in the high-response case, the full 3 MMB/D shortfall was replaced by the end of the 5 years; in the low-response case only half of the initial shortfall was replaced within 5 years. In both cases, however, net shortfalls persist throughout the 5 years before the requisite adjustments in oil use are made.

The net oil supply shortfalls were projected to induce significant economic losses over the 5-year period. In the high-response case, the permanent loss of oil imports lowered GNP on the average by about 3.5 percent from its baseline level, with a maximum yearly loss of 5 percent in the second year after the start of the disruption. In the low-response case the average GNP loss was about 6.2 percent, with a maximum yearly loss of about 10 percent also occurring in the second year after the disruption begins. In both cases, the GNP rebounds toward the end of the 5-year period because investments in oil replacement have reduced the burden of high energy costs on the economy.

Although GNP was projected to decline only in the second year after the shortfall begins, the decline in the high-response case was only 1.3 percent from the previous year, while it was 5.2 percent in the low-response case. By comparison, in 1982 the worst recession since the Great Depression resulted in a real GNP decline of 1.7 percent relative to its level in 1981. In other words, the losses projected for the high-response case are within recent historical experience, while those projected for the low-response case were well outside of it.

Differences Between the 1984 and the 1991 Assessments

World Conditions

Although many aspects of the world oil market and oil vulnerability remain qualitatively similar to conditions that existed in 1984, there are some important quantitative differences. The world and the United States still rely heavily on oil as an energy source and a significant fraction of world oil supplies continues to come from the Persian Gulf. On the other hand, because of growth in the U.S. economy (about a 20-percent increase after accounting for inflation), very little increase in oil consumption, and lower oil prices (about 50-percent decline in real terms), the share of U.S. GNP devoted to oil purchases in 1991 has declined to about 40-percent of its value in 1983. This makes any dollar increase in the price of oil cost the United States economy less now than in 1983.

Partially offsetting the moderating effect of a lower share for oil in the economy, is the recent increase in the share of the world's oil coming from the Persian Gulf. This is a result of the increase in the share of oil that is imported by the United States (the U.S. net import share of consumption has increased from about 30 percent of total U.S. oil consumption in 1983 to about 42 percent today) and other oil importers. The concentration of low-cost oil reserves in the Persian Gulf will likely mean steady increases in the Gulf share over the next decade. Since the region is politically unstable, the more oil it produces, the larger the oil supply interruption resulting from any initiating event. And the larger the shortfall, the larger the world oil price increase required to bring world oil supply and demand back into balance.

A final difference in conditions since 1984 is that a large 5-year interruption in oil supplies now seems less likely, owing to the increase in the number of oil exporters as well as the recently demonstrated propensity of the remaining producers to try to make up shortfalls.

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[4] U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-244 (Washington, D.C.: U.S. Government Printing Office, September 1984).

Methodology

There were several key differences in the method OTA used to calculate the economic impacts of the oil shortfalls, with and without oil replacement initiatives. These differences were the result of more limited resources and less time available for the 1991 study, changes in world oil and economic conditions, the opportunity to study the impacts of oil shocks since 1984, and the differences in the technical oil replacement analyses used by OTA as inputs. The two most significant differences are the way the responses to the oil supply reductions are represented and the way post-shortfall oil prices are computed. These differences are described here briefly in order to set the stage for the technical analysis that follows.

The 1984 analysis used a multisector input-output model to trace the impact of the oil shortfall on interindustry activity. Industrial and utility boiler oil replacement measures were used to adjust input-output coefficients and sectoral demands directly, while prices were increased until reductions in transport, residential, commercial, and nonboiler industrial uses achieved the remaining required overall shortfall in demand. In the present analysis, all oil demands are aggregated and the replacement policies are assumed to reduce the level of oil demand at any price, reducing the price increase required to rebalance the oil market for a given reduction in U.S. oil supply availability. In this regard the 1984 analysis was more detailed than the present one.

In the 1984 analysis it was assumed that the U.S. share of the world oil shortfall would be that derived from the International Energy Agency's (IEA) emergency sharing rules. Many analysts now believe that since those rules allocate much of the reduction in accordance with preinterruption import shares, those reductions would not be consistent with a market response, which would tend to allocate them more in accordance with consumption shares. In addition, a non-OPEC increase in production would be expected if an OPEC shortfall were to persist over a 5-year period. Thus, in the 1991 analysis, the price of oil is adjusted on a worldwide basis rather than a U.S.-only basis. This tends to make the U.S. oil import reductions smaller, but also makes the U.S. oil replacement policies somewhat less effective in reducing the U.S. economic impacts of the assumed world oil shortfall.

Analysis of the Economic Impacts of an Oil Replacement Strategy, 1991

For this report, OTA did not conduct an extensive analysis of the economic impacts of the 5 MMB/D disruption scenario. Instead, we have based our analysis on a number of other studies of oil markets and the economic impacts of disruptions, including several by Stanford University's Energy Modeling Forum. These studies provide a useful perspective from which to derive approximate estimates of the impacts that might be obtained from more comprehensive modeling of the key energy and economic relationships. The approach used in this study is briefly described here.[5]

Disruption Size

Since oil is easily traded internationally, the impact of a disruption on any economy (including that of the United States) must be estimated from world oil market conditions. All economies face the same increase in oil prices, which will be governed by the share of world oil production lost during the disruption and how much price increases augment supply and curtail demand after the disruption. The U.S. dependence on oil imports will not directly determine how high oil prices will move in a disruption or in response to a U.S. oil replacement policy.

This situation means that the economic impact of a disruption must be determined from world rather than U.S. oil market conditions. It is assumed that all of the 16 MMB/D of Persian Gulf oil is lost to the world market for an extended period of 5 years. The lost production represents almost a 30-percent shortfall for a world oil market using 53 MMB/D in the second year, although the shortfall will be partly offset by the increase in world oil supplies from non-OPEC regions induced by the higher prices of the sustained disruption. Accordingly, the U.S. economy will share proportionately in this world shortfall of 30 percent, unless supply and demand responses to prices vary significantly across countries. For purposes of this analysis, we estimate that an initial 16 MMB/D disruption removes about 4 MMB/D of oil from the U.S. economy, after accounting for the expected production offsets from supply regions outside OPEC. Ignoring this additional supply response will lead to an overestimate of the economic losses resulting from the disruption. Note that this total shortfall of 4 MMB/D is less than that assumed in the oil disruption scenario used in chapter 3, which assumes no additional imports from alternative suppliers.

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[5] The details of the analysis are contained in Hillard G. Huntington and John P. Weyant, "Economic Impacts of U.S. Oil Replacement Policies: Methodology and Results for the OTA Analysis," OTA contractor report, April 1991.

The responses of supply and demand to price and income were chosen on the basis of a number of studies of these parameters, with particular emphasis given to a 1991 Energy Modeling Forum study on international oil supplies and demands[6]

Changes in Real GNP

The mechanisms through which oil prices can affect the economy are numerous and are best represented by a fully articulated model of the national economy. In this chapter, we provide an estimate of the impact through the use of a single parameter linking oil price changes with declines in real GNP. This parameter has been chosen on the basis of past simulations of more than a dozen models in a previous Stanford Energy Modeling Forum (EMF) study.[7] Oil expenditures as a share of GNP are currently about 40 percent of their share in 1983 (when the EMF study was conducted) at a price of about $17 per barrel (bbl). As a result, the earlier EMF estimates of these elasticities have been scaled down accordingly. In the current analysis, a 10-percent sustained oil price increase is assumed to reduce the level of real output (GNP) by 0.4 percent after 2 years and by 0.2 percent after 5 years. The impact becomes smaller over time, reflecting the economy's increased capacity for adjusting to less oil.

Changes in Real National Income

Changes in real national income include changes in physical output (GNP) as well as changes in the purchasing power of the income received for producing those goods and services.[8] The latter has been estimated as the changes in the Nation's oil import bill due to higher oil prices. They are calculated from changes in the oil price (see above) and from the levels of U.S. production and consumption both before and after the disruption. Adjustments in oil demand and supply levels as a result of the disruption are derived from estimates of the response of supply and demand to price changes, available from the Energy Modeling Forum study on international oil supplies and demands mentioned above.

Results

The lost oil production and its effect on oil prices for the disruption scenario are summarized in the first two columns of table 4-1. Although there exists considerable uncertainty about how high oil prices would rise during a disruption, these estimates are representative of others made for similarly sized oil disruptions.

The sustained disruption would push oil prices from an assumed $22/bbl in the baseline, held constant over the next 5 years, to about $50/bbl after 2 years and to about $44/bbl after 5 years.[9] Prices in the very short run, of course, could be considerably higher, particularly since these estimates ignore such issues as oil trading and stockpiling dynamics.

A second scenario combines the sustained disruption with an aggressive U.S. policy toward replacing oil use. Based on the deployment schedule provided in the technical analysis of the oil-replacement technologies, the policy is assumed to reduce U.S. oil use by 1.4 MMB/D at any oil price in the second year and by 3.0 MMB/D in the fifth year. It is assumed that the policy does not displace any oil consumption that would ordinarily be curtailed as a result of the higher prices of a disruption and that it successfully targets the most cost-effective opportunities within this subset of technologies. These assumptions give the oil replacement policy its most favorable impact on oil prices. As shown in the last two columns of table 4-1, the oil replacement policy causes the world oil price to rise less than in the initial scenario. As with the disruption-only case, these effects must be calculated from world oil rather than U.S. market condi-

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[6] Energy Modeling Forum, *International Oil Supplies and Demands*, EMF Report 11 (Stanford, CA, Stanford University, 1991).

[7] Energy Modeling Forum, *Macroeconomic Impact of Energy Shocks*, EMF Report 7 (Stanford, CA, Stanford University, 1985).

[8] The real national income results also include some estimates of the cost of the oil replacement policy, which requires capital and other inputs to be diverted from other sectors to reduce oil use beyond the level that would be selected by market participants responding to price alone. The reduction in national income caused by this shift is not incorporated in the earlier estimates of the real GNP loss, which were a function of oil price changes only. It is estimated that the oil replacement policy would require that an additional $13.7 billion of national income be spent during the second year, and an additional $19.7 billion in the fifth year. These costs could be substantially higher if the oil replacement program targeted investments that turned out to be more expensive.

[9] All prices are in constant 1990 U.S. dollars.

Table 4-1—Disruption Size and Oil Price Impacts MMB/D and Prices in 1990 $/barrel

	Sustained oil disruption		Disruption with oil replacement	
	Second year	Fifth year	Second year	Fifth year
Supply disruption:				
World oil supply*	16.0 MMB/D	16.0 MMB/D	16.0 MMB/D	16.0 MMB/D
U.S. replacement policy	0.0 MMB/D	0.0 MMB/D	1.4 MMB/D	3.0 MMB/D
Net world shortfall	16.0 MMB/D	16.0 MMB/D	14.6 MMB/D	13.0 MMB/D
Percent of world*	30.2%	29.3%	27.5%	23.8%
Oil price increase	125.8%	97.5%	114.8%	79.2%
Disrupted price	$49.7	$43.5	$47.3	$39.4
Baseline price	$22.0	$22.0	$22.0	$22.0

*Excluding U.S.S.R., People's Republic of China, and Eastern Europe.

NOTE: MMB/D = million barrels per day

SOURCE: Hillard G. Huntington and John P. Weyant, "Economic Impacts of Oil Replacement Policies: Methodology and Results for the OTA Analysis," OTA contractor report, April 1991.

tions because oil can be easily traded between regions. The policy of replacing 1.4 MMB/D of U.S. oil use reduces the net world shortfall of the disruption to 14.6 MMB/D, or about 27.5 percent of world baseline consumption of 53 MMB/D in the second year. Oil prices after 2 years rise from $22/bbl to about $47/bbl in this case. Relative to the disruption-only case, the U.S. policy reduces the price shock by an additional $2.40/bbl after 2 years and an additional $4/bbl or so after 5 years. The incremental effects of the policy are relatively modest because the U.S. policy is relatively small in the context of world oil production and consumption.

Table 4-2 contains the estimates of losses in real GNP and real national income in both scenarios. Real GNP would be sharply reduced by a sustained disruption of Persian Gulf oil, declining 5 percent below its baseline after 2 years and 2 percent below after 5 years. The GNP loss after 2 years would be substantially larger than those experienced during past oil price shocks. The National Petroleum Council estimated GNP losses to be 2.7 percent from the 1973 disruption and 3.6 percent from the 1979 shock.[10] An accelerated U.S. oil replacement policy would mitigate the losses from a sustained disruption somewhat, but the level of GNP would still fall by 4.6 percent and 1.6 percent, respectively, for these two years. The incremental effect of the policy would be to restore about 0.4 percent of real GNP in each year.

The broader measure of real national income shows larger losses from a disruption than does real GNP, because it incorporates the effect of higher oil prices on domestic purchasing power. Conclusions about the effectiveness of the oil-replacement policy, however, remain similar to those based on the real GNP results. In the second year of the sustained disruption, real national income would be 6.3 percent lower than the baseline without the oil replacement policy and 5.6 percent lower with the oil replacement policy. By the fifth year, real national income would be 3.0 percent lower without the policy and 2.1 percent lower with the policy.

These results suggest that the policy could provide some modest benefits in both real output and real national income, depending on how it is implemented. We have attributed to the policy its largest impact on oil prices because it is assumed to displace only oil use that would not already be displaced by higher prices during a disruption. In addition, it is assumed that the policy targets only the most cost-effective opportunities for replacing oil that remain after the disruption. While these assumptions have represented the policy in its most favorable form, the analysis has not incorporated any potential economic gains from removing barriers that result in inefficient use of energy, labor, and capital. It is unclear whether oil replacement policies would lead to such gains, but if they do, they would produce additional benefits that

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[10] National Petroleum Council, *Factors Affecting U.S. Oil and Gas Outlook* (Washington, DC: February 1987).

Table 4-2—Comparison of U.S. Economic Impacts of a Sustained Oil Disruption and an Oil Replacement Strategy

	Sustained oil disruption		Disruption with oil replacement	
	Second year	Fifth year	Second year	Fifth year
Percent change in the level of:				
Real GNP	–5.0%	–2.0%	–4.6%	–1.6%
Real national income	–6.3%	–3.0%	–5.6%	–2.1%

NOTE: Changes in real GNP, as conventionally measured in the national income accounts, represent changes in physical output. Changes in real national income includes changes in the purchasing power of the income received from producing that output

SOURCE: Hillard G. Huntington and John P. Weyant, "Economic Impacts of Oil Replacement Policies: Methodology and Results for the OTA Analysis," OTA contractor report, April 1991.

have not been incorporated here because they are difficult to quantify. A more refined evaluation of the oil-replacement costs would require additional information on the cost effectiveness of different oil replacement strategies as well as an estimate of how much of the oil replacement is induced by higher prices during the disruption and how much remains to be implemented even after the higher prices.

The estimates of the economic impact of a disruption are sensitive to several key assumptions. The reported losses would be higher when: 1) oil demands and supplies are less responsive to price, or 2) the impact of oil prices on real GNP is larger. However, the relative costs of implementing an accelerated U.S. oil replacement policy during a sustained disruption are quite insensitive to these assumptions. Instead, the relative merits of the policy depend critically on assumptions about how it is implemented. It will be most effective: 1) when the policy is targeted toward the least costly technologies, and 2) when the policy is adopted simultaneously by all countries rather than implemented unilaterally.

Further Research

A more comprehensive evaluation of the oil replacement policy would require three analytical components:

1. a representation of world oil markets and their responses to changed conditions,
2. a model of the U.S. economy that can incorporate some data on alternative technologies, and
3. a detailed assessment of oil replacement technologies that developed estimates of how much oil could be replaced at successively higher costs.

The world oil market conditions have been represented quite simply in the current analysis by extracting key parameters from more extensive studies of these models. An alternative approach would be to base the analysis of world oil conditions on a single model, like the Energy Information Administration's Oil Market Simulator (OMS) system. Given that both approaches are readily available, this aspect of the analysis would not require extensive further development.

For estimating the economic impacts on the U.S. economy, a macroeconomic model that represents the relationship between inputs and outputs in individual industries could be used.[11] Such a framework allows the technical characteristics of the major oil replacement options to be explicitly represented. Many macroeconomic models focus on aggregate economic conditions and do not include a detailed accounting of industrial input needs.

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[11] Two suitable approaches are the input-output framework, which is embedded in the INFORUM model used in OTA's 1984 analysis, and the general equilibrium approach, which has been pioneered by Professor Jorgenson in his Dynamic General Equilibrium Model (DGEM). See D. Jorgenson, "Econometric and Process Analysis Models for Energy Policy Assessments," in R. Amit and M. Avriel (eds.) *Perspective of Resource Policy Modelling: Energy and Minerals* (Cambridge, MA: Ballinger, 1982).

Finally, it is important that future estimates of the oil replacement potential carefully consider not only the amount of oil replaced but also the costs of implementing these technologies, using consistent economic assumptions across the various options. When oil prices rise during a disruption, some options will be chosen in response to the new market conditions and, therefore, no new policy initiatives will be needed. Other options will not be chosen even at the higher prices. A more comprehensive analysis of an oil replacement policy must differentiate between these two types of opportunities.

CONCLUSION

Future oil disruptions will continue to pose a serious threat to U.S. economic activity. Although the U.S. reliance on oil to power its economy has declined over the last two decades, the world has become increasingly more dependent on oil supplies from the Persian Gulf, and virtually all experts expect this dependence to grow over time.

As estimated in this chapter, real GNP would be sharply reduced by a sustained disruption of Persian Gulf oil, declining 5 percent below its baseline after 2 years and 2 percent below after 5 years. An accelerated U.S. oil replacement policy would mitigate the losses due to a sustained disruption somewhat, but the level of GNP would still fall by 4.6 and 1.6 percent, respectively, for these 2 years. The incremental effect of the policy, therefore, is to restore about 0.4 percent of real GNP in each year.

Implementation issues remain critical to the potential success of an accelerated oil replacement policy. The policy would provide more economic benefits than estimated here if the U.S. action were coord–inated with similar policies in other countries. It would be less effective than estimated here if the policy failed to target the most cost-effective technologies.

Chapter 5

U.S. Energy Policy and Technologies for Replacing Imported Oil

Contents

Page

INTRODUCTION 115

Policy Considerations 115

POLICY OPTIONS FOR REPLACING OIL IN AN OIL SUPPLY DISRUPTION 117

Residential and Commercial Sectors 117

Electric Utility Sector 120

Industrial Sector 122

Transportation Sector 123

Encouraging Domestic Oil and Gas Production 126

Enhancing Natural Gas Availability 127

Reexamining Oil Import Disruption Planning and Emergency Response 127

POLICY OPTIONS FOR REDUCING OIL IMPORT VULNERABILITY AS PART OF OTHER NATIONAL POLICY OBJECTIVES 128

Setting National Energy Policy Goals 128

CONCLUSION 131

Chapter 5

U.S. Energy Policy and Technologies for Replacing Imported Oil

INTRODUCTION

The United States faces a future of growing dependence on imported oil and an ever-increasing vulnerability to oil supply and price disruptions on world markets unless effective countervailing measures are taken to reduce these risks. Technologies available today can lessen our vulnerability: some are cost-competitive with oil now; others would be so at higher oil prices. However, with demand for oil growing and domestic production declining, it is no longer possible to rely on technical means alone to replace a significant share of lost oil imports in a prolonged supply disruption. Moreover, in addition to enhancing our energy security, acceptable oil replacement technologies will have to be compatible with other policy goals such as environmental protection and international competitiveness.

This chapter examines policies and strategies for countering increased oil import vulnerability. It begins with a discussion of key policy considerations in crafting effective legislative options and follows with a brief discussion of some policy options for promoting the adoption of oil replacement technologies: 1) in response to or in the event of a major oil supply disruption and 2) as part of a more general national energy strategy.

This report does not examine any of these policy options in depth, or evaluate the best methods of implementation, or quantify the potential costs and benefits. If Congress decides to pursue these measures, it might use the legislative process to elicit this information from the Department of Energy (DOE), energy industries, States, and academic and other experts; or, as part of a phased implementation strategy, Congress could require DOE to investigate and report on optimum policies, and expected costs and benefits.

Policy Considerations

In developing appropriate legislative responses to the problems posed by growing oil imports, it is important to distinguish between *oil import dependence* and *oil import vulnerability*. Import dependence is measured as the percent of domestic consumption that is met by foreign oil. In 1990 about 42 percent of our oil needs came from foreign sources.[1] A rising level of imports contributes to import vulnerability, but import dependence alone does not translate into a serious threat to energy security.

Import vulnerability arises out of the degree and nature of import dependence, the potential harm to the economic and social welfare of a severe disruption in physical supplies or prices, its duration, and the likelihood of such a disruption occurring. An increase in oil import dependence does not by itself generate an equal increase in oil import vulnerability.

Understanding the components of import vulnerability allows the targeting of effective countermeasures. For example, oil is now a fungible and freely traded commodity on world markets. Crude oil prices will continue to be set in world markets regardless of the extent of U.S. oil import dependence. Unlike the situation prevailing in the 1970s, oil prices in the United States are virtually unregulated. They move freely with changes in world market prices. With the rapid growth of oil spot and futures markets, and the changes in the terms of oil contracts to set delivered prices based on these posted prices, oil prices can be very volatile. Changes in supply (or rumors of changes in supply) are reflected almost instantly in world prices. The consequences of this structural change in the oil industry were brought painfully home to consuming nations in the aftermath of Iraq's invasion of Kuwait.

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[1] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review: February 1991*, DOE/EIA-0035(91/02) (Washington, DC: U.S. Government Printing Office, February 1991), tables 3.1a & 3.1b.

Growth in oil import dependence has its costs; for example, higher import levels can make it more difficult for the United States to adjust to price or supply disruptions and require increased U.S. exports or changes in the international value of the U.S. dollar to pay for the imports.[2] On the other hand, oil imports have some positive aspects. First, they may provide a ready supply of cheap oil, benefiting U.S. consumers and oil-intensive industries. Second, U.S. oil companies are actively involved in oil exploration and production in foreign countries and derive a significant share of their revenues and profits from foreign operations, which in turn depend on exports to the United States and other consuming nations. Third, U.S. oil equipment manufacturers and oil service companies are also active in foreign countries. Fourth, U.S. imports offer a potential outlet for alternative supply sources outside of the politically volatile Middle East. Diversification of world oil production reduces that region's control of world supplies and, thus, enhances U.S. energy security. Fifth, the growth of oil and gas industries in many developing countries has spurred economic development and provides an important source of foreign exchange that allows those countries to import goods and services to improve the lives of their citizens. The United States has supported their development efforts through foreign assistance programs and international organizations. Sixth, many of the our major oil suppliers are nations with whom we have developed important and strategic relationships that go well beyond reliance on oil (Canada, Mexico, Venezuela, Saudi Arabia, the United Kingdom, and Norway, for example). Efforts targeted at cutting oil imports could damage these relationships with usually stable suppliers.

One way of reducing oil import vulnerability would be to cut the level of imports, but reducing imports alone poses questions of practicality and effectiveness. No one has seriously suggested that in the near term, by 2010, or later that the United States could or is willing to pay the costs of fully replacing imports with a combination of domestic production, fuel switching, alternative fuels, demand reduction, and efficiency improvements. President Bush's National Energy Strategy projects that the United States will become even more dependent on Middle Eastern oil imports in the future even if all of the strategy's proposals are implemented.[3] Moreover, even if we succeeded in replacing imports, we would still remain vulnerable to oil price disruptions as long as oil prices continue to be set in potentially volatile world markets (although the extent of vulnerability may be reduced because oil might lose some of its importance in the overall economy). Clearly, this is an area where a delicate balancing act is called for.

The United States has already taken a number of steps to offset import vulnerability. Chief among these, and the first line of defense for supply disruptions, is the Strategic Petroleum Reserve (SPR), the government-held stockpile of crude oil intended to supply at least 90 days worth of U.S. oil imports in the event of an oil emergency. The United States is also party to International Energy Agency (IEA) agreements on international oil supply emergencies that commit members to maintain strategic stockpiles, develop standby demand reduction plans, and to share oil supplies in a shortage. In early 1991, Operation Desert Storm triggered an IEA-coordinated release of government-held strategic stocks to counter possible market impacts of allied action against Iraq.

Other government actions, such as corporate average fuel economy (CAFE) standards for automobiles and light trucks, fuel use restrictions, purchase and interconnection requirements for qualifying cogeneration and small power producers under the Public Utilities Regulatory Policies Act (PURPA), and federally funded energy technology research, development, and demonstration (RD&D) programs, have combined with price signals to help the United States make great progress in reducing the oil intensity of the economy and in using oil more efficiently. Independently of government programs, businesses, utilities, and individuals have significantly reduced their own vulnerability to the consequences of oil supply or price disruptions through, for example, dual fuel capability and efficiency improvements. One consequence of this success, however, is that the easy steps have already been taken and replacing the remaining uses of oil has become increasingly more difficult.

If Congress decides to reduce oil import vulnerability by displacing oil use or enhancing our technical readiness for replacing imports, there are a number of potentially effective measures available. No single technology will eliminate oil import dependence and no quick fixes will eliminate oil import vulnerability. An effective strategy will require a combination of oil replacement initiatives, perhaps combined with other energy and environmental policy measures.

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[2] National Petroleum Council, *Factors Affecting U.S. Oil and Gas Outlook*, February 1987, p. 7.

[3] *National Energy Strategy: Powerful Ideas for America, First Edition 1991/1992* (Washington, DC: U.S. Government Printing Office, February 1991).

To illustrate how oil replacement technologies might contribute to the goal of reduced oil import vulnerability, we present two strategies:

- promoting the adoption of oil replacement technologies in an oil supply disruption, and
- reducing oil import vulnerability as part of long-term national energy policy objectives.

Both strategies rely on many of the same oil replacement technologies and policy initiatives. One critical difference is that some policy options and technologies have fewer implementation problems and offer greater oil savings if adopted as part of a long-term oil replacement strategy rather than as part of a crisis-driven strategy.

POLICY OPTIONS FOR REPLACING OIL IN AN OIL SUPPLY DISRUPTION

A variety of policy measures could reduce oil use either by improving energy efficiency or by encouraging conversions to other fuels. This section presents such policy options for each energy sector. In addition, options for improving the domestic supply of oil and for enhancing emergency response measures are explored.

Residential and Commercial Sectors

Replacement of most oil use in the residential and commercial sectors is technically feasible; however, the success of such a strategy will depend on individual decisions by millions of consumers. It is already abundantly apparent that price alone is insufficient to achieve reductions because many oil savings technologies are already cost-effective. A number of institutional and technical constraints have discouraged oil replacement and energy efficiency improvements in these sectors.[4] There are, however, policy initiatives than can be targeted to overcome these financial, informational, cost, and institutional constraints.

Several financial disincentives are at work. First, residential and commercial oil demand is highly inelastic. (Price elasticity measures the change in energy demand in response to the change in the price of energy. Inelastic demand is insensitive to price changes—i.e., it does not change much or quickly when prices go up or down.)[5] Thus, oil prices would have to rise dramatically over the costs of competing fuels to trigger enough replacements or retrofits to have significant oil savings. Analyses vary about what level of price increase would suffice.[6]

Second, residential and commercial customers are generally highly sensitive to front-end costs. High front-end costs and cash flow considerations can deter them from making conversions and efficiency improvements that offer lower life cycle costs. This is true even for measures with relatively short payback periods of 4 years or less.

Third, this preference for low front-end costs is amplified for equipment and efficiency decisions for new construction, rehabilitation, and rental properties where those making initial purchase decisions are often not the ones who will be paying the fuel and operating costs.

Finally, the structure of the residential-commercial fuel supply network does not encourage fuel suppliers to promote efficiency, except out of fear of loss of market share to competing fuels.[7] Their revenues, after all, depend on the volume of sales. This is in marked contrast to the many regulated electric and gas utilities that have aggressive conservation programs as part of demand-side management strategies or in response to State regulatory program directives or financial incentives. Despite these disincentives, it should be noted that the energy efficiency of new homes and commercial buildings is much higher than that of older stock.

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[4] OTA has an ongoing project investigating overall energy efficiency in the residential and commercial sectors which examines both institutional and technological issues in more detail. The institutional aspects of promoting energy efficiency and reduced emissions of pollutants in the buildings sector and related policy options are also examined in another OTA report: U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), ch. 4. Hereinafter referred to as *Changing by Degrees*.

[5] See ch. 4 of this report for a discussion of the response of the U.S. economy to oil price changes.

[6] *Changing by Degrees*, supra note 4 at pp. 135-137, and cited references.

[7] For example during the fall and early winter of 1990-91, fuel oil distributors mounted an aggressive advertising campaign citing the high costs of converting to natural gas and the perceived relative safety of fuel oil, even at higher costs.

Many building owners have already made some improvements in energy efficiency. However, while DOE survey data suggest that still more incremental savings are possible,[8] it is not clear how many of these measures are attractive at today's energy prices. Some analysts have attributed the lag in savings in part to a lack of information about the potential from building efficiency improvements and better equipment.

A key uncertainty in converting existing oil furnaces, boilers, and water heaters to natural gas is the limited availability of natural gas in some areas. This constraint is due to: the extent of local gas distribution companies' service infrastructure, the seasonal availability of gas supplies, and insufficient interstate natural gas pipeline capacity and gas storage facilities to meet potential demand.

Under normal conditions, the pace of energy conservation and oil conversions in the residential and commercial sectors is slow because so much is determined by the characteristics of the existing buildings and equipment. To get residential and commercial building owners to accelerate oil conversions and efficiency improvements in an oil emergency will require a mix of information, exhortation, direct financial incentives, and voluntary and mandatory efficiency standards. Legislative options to foster oil savings in the residential and commercial sectors include: options affecting fuel prices and availability, measures to reduce front-end costs and cash flow barriers, financing assistance, efficiency standards, public information (labeling and certification programs), and technology RD&D programs. There is not extensive experience with most of these measures under normal conditions, and little conclusive analysis of their effectiveness. Some of these measures may provide only marginal oil savings over the short term, but may be more effective over a longer period of time.

Making Oil Use More Expensive

Discouraging oil use by making it more expensive through the imposition of oil surcharges, fees, or taxes has frequently been advocated. The relatively higher oil taxes paid by European and Japanese consumers and their, presumably more efficient, lower per capita oil use are often cited as support for this approach. Other purposes for imposing such surcharges include: conserving oil, reducing oil imports, raising Federal revenues to pay for specific programs or to cut the deficit, and correcting market failures that keep oil prices low by excluding the full cost of various externalities in oil use.

In addition to the financial disincentives previously discussed, this approach has several drawbacks as an effective option for encouraging near-term oil replacement in response to an import crisis. First, such surcharges tend to be regressive, burdening lower income families more than affluent households. Second, higher oil prices would frustrate other energy assistance programs by reducing the impact of already limited Federal, State, and local resources for helping the poor pay their energy bills. Third, and perhaps most significantly, raising fuel costs even higher than the levels already triggered by an oil shortage could exacerbate the economic effects of the crisis. These results could be politically unacceptable. While it is possible to include mechanisms to offset the regressive features of a surcharge, such as tax credits or rebates, the overall economic impacts of higher oil prices would remain controversial.

Reducing Front-End Costs and Cash Barriers

Rebates, tax credits, tax deductions and other mechanisms for cutting up-front costs of oil conversions or efficiency improvements would appear to be attractive ways of countering financial disincentives. However, experience with these as measures for displacing oil use is limited.

Rebates on the purchase and installation of oil-saving measures might be comparable to customer rebates in utility demand-side management programs. Some have suggested that the rebates be coupled with and financed by an initial purchase tax on inefficient equipment, or even on buildings.[9] It is not clear whether such a program would be adequately self-financing if directed only at oil use, or if it would actually be effective in shifting purchase decisions to more efficient products or structures. Also uncertain is who would administer an oil-savings rebate program—utilities, fuel oil suppliers, State agencies, or the Federal Government.

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[8] For additional insight into the complicated nature of determining the cost-effectiveness of some available building efficiency retrofits, see the discussion in U.S. Congress, Office of Technology Assessment, *Energy Efficiency of Buildings in Cities*, OTA-E-168 (Springfield, VA: National Technical Information Service, March 1982).

Congress could consider allowing property owners (and tenants, in some instances) to deduct or credit against their income taxes some or all of the costs of installing oil replacement equipment or qualified efficiency improvements such as increased insulation, storm windows, and flame retention burners. However, studies of the effectiveness of the residential energy and solar tax credits were inconclusive about its success in spurring incremental investments that would not otherwise have been made.[10] Some analysts argue that the tax credits had little or no incremental benefit and amounted to a windfall for certain taxpayers; others suggest that the credit was too low to be effective, or that the increase in energy prices dwarfed the effects of the tax incentive. To be effective, great care would have to be taken in creating appropriate tax incentives to trigger incremental investments in oil savings.

Financing Energy Savings

Congress might also consider enacting or expanding mechanisms, such as grants, loans, loan guarantees, and shared energy savings programs, to aid the financing of conversions and efficiency improvements. Federal law already provides a variety of mechanisms that might be useful.[11] OTA has not investigated how much additional oil savings they might provide and at what cost.

Setting Energy Efficiency Standards

Congress could encourage measures affecting the availability of efficient equipment and the energy efficiency of buildings, such as voluntary and mandatory equipment standards, energy rating systems, product certifications, and building codes. Coupled with other incentives to trigger oil conversions and efficiency improvements, these measures could help assure that investments in these technologies achieve optimum oil savings by providing pertinent information to consumers and keeping inefficient products out of the marketplace. The Federal Government has cooperated in developing model building codes that promote energy-efficient construction and is committed to encouraging States to adopt these requirements. Efficiency standards for furnaces and water heaters are mandated under the National Appliance Energy Conservation Act of 1987 (Public Law 100-12). For example, the annual fuel utilization efficiency (AFUE) standard for oil boilers effective in 1992 is 78 percent, yet there are many models commercially available today approaching 90 percent AFUE.[12] Such minimum efficiency standards and codes could be made more stringent or accelerated in an oil emergency.

In response to a crisis, Congress could either restrict oil use in or require replacement of oil-burning equipment in large residential and commercial buildings or complexes after a specified transition period. Mandating equipment replacement in private homes and small commercial buildings, however, would be more difficult and controversial, and oil savings might better be achieved through a combination of incentives and other measures. For example, Congress might require that new or existing homes must either replace oil-burning equipment or achieve a prescribed building efficiency rating to qualify for federally backed mortgages or as a condition of sale. Congress could direct States to consider additional measures to cut residential oil use.

Improving Public Information

Other measures that enhance the availability and quality of consumer information on oil savings technologies, such as appliance labeling, energy rating systems for buildings, energy audits, and energy conservation assistance programs, could help building owners and tenants learn about potential cost-effective oil savings. Such promotional efforts could improve the effectiveness of voluntary conservation.

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[9] For more on such proposals, see *Changing by Degrees*, supra note 4, ch. 4.

[10] Eric Hirst, Richard Goeltz, Hyldee Manning, "Household Retrofit Expenditures and the Federal Residential Energy Conservation Tax Credit," ORNL/CON-95 (Oak Ridge, TN: Oak Ridge National Laboratory, July 1982). Salvatore Lazzari, "Are the Residential Energy Tax Credits an Effective Tool of Energy Conservation," *Congressional Research Service Review*, vol. 4, March 1983, pp. 11-13.

[11] *Changing by Degrees*, supra note 4, ch. 4.

[12] American Council for an Energy Efficient Economy, "Handbook on Energy Efficient Appliances," at pp. 24-25.

Improving the Availability of Natural Gas

A critical uncertainty in achieving a high degree of residential and commercial oil replacement is the availability and deliverability of natural gas for space and water heating systems. While there appears to be sufficient production capacity to meet increased residential and commercial demand, local gas systems in some areas would not be able to accommodate the flood of new customers without significant investments in additional infrastructure for distribution and storage and commitments of expanded delivery capability from interstate pipelines. Without a more detailed examination of the natural gas supply system, we cannot suggest specific legislative actions that could remedy this situation. Congress may wish to consider directing the Secretary of Energy, in consultation with State regulatory authorities, to study the matter further and to report on the capability of gas distribution companies to expand their services as a means of replacing oil, and to delineate any needed Federal actions to enhance this capability. Additional measures to improve gas availability are discussed later in this chapter.

Providing Federal Assistance for Technology Development

The Federal Government could assist in RD&D and commercialization of technologies that hold promise for rapid oil savings in the residential and commercial sectors either by redirecting or by adding to existing Federal energy and housing research programs. For example, further investigation of technical and institutional matters associated with converting oil boilers to burn coal slurry fuel during an oil emergency would seem fruitful. Improvement of cost-effective and quickly installed devices for retrofitting oil burning hydronic heating systems to accommodate other fuels or to enhance efficiency would also seem particularly attractive, given the large number of residential units that would benefit.

Electric Utility Sector

Although it is technically feasible to back out virtually all use of residual oil in the electric utility sector, it is not clear whether an aggressive backout would be necessary or desirable, even in a major oil import disruption. High oil prices, new capacity, demand management programs, State regulatory policies, and Federal programs under PURPA and the Powerplant and Industrial Fuel Use Act (PIFUA) already have cut oil use by electric utilities.[13] Most oil-dependent utilities now appear well situated to respond to an oil supply emergency. Nevertheless, several legislative actions could further enhance oil displacement capability and oversight in this sector if Congress wanted to speed a shift away from oil-fired generation and promote greater flexibility in responding to supply disruptions.

Electric Utility Regulation

State regulatory agencies have the primary responsibility for overseeing electric utility generation and transmission capacity planning, operations, and retail rate matters. Nevertheless, Congress has, under PURPA for example, enacted legislation influencing how States exercise their regulatory authority. Congress might consider further legislative actions now to reduce vulnerability of electric utilities in a future oil import crisis. Possible actions include the following:

- State public utility commissions (and unregulated utilities) could be required to consider oil-supply emergency responses in their contingency and capacity planning, if they do not already do so, and to consider giving preferences to oil displacement technologies (including demand and supply-side management) in the selection of new generating capacity or power supplies.

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[13] The electric utility industry is highly regulated with jurisdiction over utility activities split between the Federal Energy Regulatory Commission and State public utility commissions. States generally have exercised supervision over capacity planning, siting, and acquisition of new generating and transmission facilities, and demand-side management programs. FERC has passed on wholesale electricity transactions, transmission agreements and fees, and set general policy guidance for State implementation of PURPA.

- The Federal Power Act could be amended to direct the Federal Energy Regulatory Commission (FERC) to accept State approved preferences for oil replacement technologies in passing on the rates, terms, and conditions of bulk power sales.
- PURPA could be modified to direct FERC to authorize States to approve a bonus payment above avoided cost for power sales by qualifying facilities (QFs) using certain State-approved oil replacement technologies.
- State public utility commissions could be required to consider amending their transmission line certification or licensing approval criteria to include improving the capability of the regional transmission system to move power to displace oil in a supply crisis, if they do not already do so.

Federal Programs and Policies

In matters of national energy policy, energy security, and Federal jurisdiction over interstate power sales, the Federal Government has a continuing role in the oversight of electric utilities. In this area, too, there are several legislative actions that might be considered to improve emergency preparedness in advance of an oil import shortfall.

- Congress might require the Secretary of Energy, in cooperation with State regulatory authorities and other appropriate Federal agencies, to study and report back on the capability of regional electric transmission systems to increase power transfers to displace oil in an import crisis and suggested measures for necessary improvements. Even though, over the past decade, there has been a clear trend away from oil use in new generating units, some analysts project that in the late 1990s electric utilities will increasingly turn to oil-fired generation if electricity demand grows and natural-gas supplies tighten.[14]
- Congress may wish to consider reimposing Federal requirements that utilities, independent power producers, and industrial facilities demonstrate that any new oil-burning units (over a certain size) be capable of modification or replacement to burn an alternate fuel within 6 to 12 months.
- Federal efforts to increase the seasonal availability of natural gas could allow greater use of gas-fired generating capacity by utilities.
- Congress could direct that federally sponsored fossil energy and clean coal programs include RD&D projects for cost-effective and short-leadtime technologies to convert oil-fired units to burn coal slurry fuels or other fuels.

Congress could review the adequacy of Federal emergency authority for responding to an oil import crisis. Among possible amendments are:

- Granting additional authority to the Secretary of Energy or the President to restrict nonessential utility oil use during oil supply emergencies.
- Requiring utilities to prepare regional transmission sharing plans to facilitate voluntary bulk power transfers to displace oil-fired generation in an oil supply emergency.
- Authorizing the FERC to order utilities to provide transmission access for oil-saving bulk power transfers for other utilities in an oil supply emergency if sufficient transmission capacity is then available, including requiring any facility upgrades or operational changes necessary to carry out the transfers.[15]
- Directing the Environmental Protection Agency (EPA) to examine applicable permit review and approval procedures for conversions of oil-burning facilities to natural gas or coal and to recommend any changes that might be needed to expedite the processing of such requests in an emergency.

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[14] This could be especially true if peak load grows faster than base load. The low capital costs and short lead-times of new oil-fired units could make them attractive if adequate supplies of natural gas are not available. It is not clear, given recent experience, that any utility would build such a single-fuel plant now unless it were redundant capacity.

[15] For a discussion of the technical and policy issues involved, see U.S. Congress, Office of Technology Assessment, *Electric Power Wheeling and Dealing: Technological Considerations for Improving Competition*, OTA-E-409 (Washington, DC: U.S. Government Printing Office, May 1989), chs. 5 and 7.

Industrial Sector

Much of industrial sector oil demand is for feedstocks and nonmanufacturing applications that currently have few replacements available. Consequently, most of the near-term oil replacement potential in this sector is in manufacturing. We believe that with additional research, oil replacement options for other industrial products and applications could be expanded.

Oil product use in manufacturing is diverse, and detailed analysis of the full extent of oil replacement potential is not possible based on the limited information available. OTA, like others, focused on opportunities in the most oil-intensive industries and found the major technical opportunities for oil savings to be fuel switching, converting industrial boilers to nonoil fuels, efficiency improvements and process changes, alternative feedstocks, and industrial and end-use consumer recycling and waste reduction.

The industrial sector is highly responsive to price. Over the past two decades, higher oil prices plus uncertainty about the availability of oil supplies led U.S. manufacturers to cut oil use and to enhance their capability for fuel switching. We believe additional opportunities for oil savings and efficiency gains still remain.[16] Policy options that may be most effective in this sector include those that would speed the adoption of more energy-efficient technologies. These include oil taxes or surcharges, tax incentives, and technology transfer efforts. Policies that advance other goals, such as waste reduction, can also create a market pull for oil replacement technologies. Given the extent of nonreplaceable oil use in this sector, attention should also be given to emergency fuel use authorities, the adequacy of government and private stockpiles, and RD&D efforts.

Creating Financial Disincentives for Oil Use

Imposition of fees, surcharges, or taxes on oil products to make them more expensive to use would probably trigger some additional conservation efforts in this sector. We have not investigated how much incremental oil replacement would occur or at what price. But a tax would also have negative effects. As noted previously, if the tax were imposed during a supply crisis, it could magnify the economic impacts of any shortage. Price is not the sole determinant in industrial oil use. Considerations of cost, fuel availability, process compatibility, equipment, and product quality may dictate continued use of oil. The added costs would particularly burden manufacturers who have limited replacement alternatives and would erode their international competitiveness if similar costs were not imposed on their foreign counterparts.

Creating Investment Incentives

OTA's report, *Industrial Energy Use*, found that, in general, policies that encouraged investment in new plant and equipment also tended to improve energy efficiency.[17] However, OTA also found that legislation directed specifically at improving energy efficiency in industry had little influence on investment decisions. Thus, for example, the targeted 10-percent energy investment tax credit in the Energy Tax Act of 1978 (Public Law 95-618, now expired) was found to have had minimal effect on the industrial sector, as did the accelerated cost recovery provisions of the Economic Recovery Tax Act of 1981 (Public Law 97-34) under then prevailing conditions of high interest rates and low demand growth. The most significant shifts in energy efficiency were found to have arisen from the availability of low-cost capital that made investment in capital-intensive technologies, such as cogeneration and heat recovery devices, more attractive. It is conceivable that in an emergency, high energy costs would make investments so attractive for major industrial oil users, that additional financial incentives would have only marginal impacts.

As in the utility sector, there are several oil replacement policies that if adopted in advance of an oil supply crisis could enhance industry flexibility in responding to an oil shortfall. In an actual oil shortage there may be few effective policy options, other than emergency oil use restrictions and allocations, that could achieve significant near-term oil savings over those triggered by higher oil prices.

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[16] OTA has a currently ongoing project on industrial energy efficiency which will include more detailed policy options.

[17] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, OTA-E-198, June 1983, available from the National Technical Information Service, Springfield, VA 22161 (order #PB 83-240 606), chs. 1 and 3.

Promoting Technology Development

The major oil-intensive industries have a vested interest in and a commitment to improving the availability of oil replacement options and their efficiency of oil use. Smaller companies and specialized manufacturers may not have the same resources for technology development. DOE's active Industrial Energy Conservation Program supports R&D, technology transfer, energy audits, and industrial energy education and outreach programs. Congress may wish to use the oversight and appropriations process to assure that DOE's programs give sufficient attention to oil-saving technologies. Congress could also encourage the inclusion of oil-saving and energy-efficient technologies in the RD&D and outreach activities of other agencies that support energy-related research of particular importance to the industrial sector, including the Department of the Interior (Bureau of Mines), the Department of Transportation (Federal Highway Administration), the Department of Commerce, and the Department of Agriculture.

Reducing Waste

Potential savings from process changes and alternative feedstocks include the recycling of plastics, used oil, and old tires. All of these have some potential oil and energy savings, although we have not examined them in detail. Recycling efforts have largely been driven by waste disposal concerns. Congress could require manufacturers of these products to establish programs to recycle a portion of their output either as a replacement for virgin material or as waste-derived products.[18] This might be coupled with restrictions on landfilling, incinerating such waste, or waste-end taxes. Because of the myriad of technical and implementation hurdles that must be overcome for significant savings to occur, this may not be a particularly effective near-term oil replacement option, and may be better suited to a long-term strategy; however, the added urgency of an oil crisis might provide the necessary impetus for government, industry, and consumer cooperation to overcome these obstacles.

Transportation Sector

The U.S. transportation sector is virtually locked into oil as its dominant fuel for all but the very very long term and faces significant challenges in cutting oil demand. Nevertheless, given the large amount of oil used (60 percent of total demand), even small improvements can make important contributions to more efficient oil use. Improving motor vehicle fuel economy and shifting from gasoline to other fuels also offer the prospect of reduced emissions of harmful pollutants.[19] The transportation sector has already made some efficiency improvements, spurred by higher prices, voluntary conservation, and government programs, but progress has not been as great as some, including, OTA, once hoped.

With aggressive conservation measures, and the cooperation of government, industry, and consumers, it is technically feasible to cut oil use in the transportation sector by over half a million barrels per day (B/D) within 5 years in response to an import crisis. An aggressive oil replacement strategy would include four goals:

1. improving light-duty vehicle (LDV) fuel efficiency,
2. accelerating the adoption of alternative non-oil transportation fuels and vehicles,
3. cutting or limiting the increase in vehicle miles traveled, and
4. improving the efficiency of traffic movement.

Achieving the full savings potential will require action by Federal, State, and local governments, cooperation by manufacturers, and a high degree of public acceptance. Because no single policy will provide the full savings, a combination of options seems warranted.

The possible policy options for implementing this strategy are varied, and many are controversial. Some of the most commonly suggested alternatives for each goal are discussed briefly below. A detailed analysis of each of these options is beyond the scope of this report; however, as noted, several of them are examined in other OTA studies.[20]

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[18] See ch. 3 of this report and U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?* OTA-E-424 (Washington, DC: U.S. Government Printing Office, October 1989).

[19] U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternatives for Light-Duty Vehicles*, OTA-E-354 (Washington, DC: U.S. Government Printing Office, June 1990).

[20] See *Replacing Gasoline*, ibid., and *Changing by Degrees*, supra note 4, ch. 5. The potential for additional improvements in auto fuel economy is being examined in a separate OTA report, *Improving Automobile Fuel Economy: New Standards, New Approaches*, scheduled for publication in October 1991.

Improving Light-Duty Vehicle Fuel Efficiency

Among the competing options for increasing LDV fuel efficiency are the following: relying on a combination of higher (shortage-induced) market prices, taxes, and rebates to create price signals that influence consumer choice; strengthening Federal fuel economy standards; and requiring fleet operators (including Federal agencies) to purchase more fuel-efficient vehicles. There is considerable debate about the relative effectiveness, political viability, and appropriate balance of these approaches.

Influencing Consumer Choice Through Price Signals— A market-oriented approach using various mechanisms to affect the front-end and life-cycle costs of cars and light trucks is based on the assumption that consumers will choose more efficient vehicles in response to such price signals. In addition to allowing gasoline prices to rise freely in response to a supply shortage, possible mechanisms include imposing significantly higher gasoline taxes, raising the gas-guzzler tax on the purchase of inefficient new vehicles, offering gas-sipper rebates for highly efficient new vehicles, and imposing fuel efficiency-based annual vehicle registration fees. (Congress raised gas guzzler taxes at the end of the 101st Congress.) Past studies on the effects of higher prices on vehicle preferences and discretionary driving are mixed, so that the effectiveness of these measures alone is uncertain. At the very least, they appear to be more effective as longer term, rather than rapid-response, measures in affecting overall fleet efficiency.[21] Tax-based measures pose the problem of setting a rate high enough to be effective while still being acceptable and nonregressive. Rebates raise questions of funding sources and potential windfalls for consumers who would have purchased efficient vehicles anyway.

Strengthening Federal Vehicle Fuel Economy Standards—Amending Federal vehicle fuel efficiency standards to require new cars and light trucks to attain maximum fuel economy levels under available technology would offer some oil savings even without substantial changes in fleet mix and consumer preference. These savings would begin to be apparent within 5 years as manufacturers accelerated the application of fuel-efficient technologies. More aggressive standards could achieve greater savings, but would entail greater uncertainties, changes in fleet mix, and more disruption of manufacturers' product plans.

Some, including OTA, have suggested that the form of the fuel economy standard can be technology forcing. For example, changing the standard from an industry-wide corporate average fuel economy standard to a volume-averaged fuel economy standard would require manufacturers to increase the efficiency of all vehicles in their product lines.[22] Requiring across-the-board increases in fuel economy has been criticized as unfairly penalizing manufacturers who have already made significant gains and who face more difficult technical hurdles than those manufacturers who have lagged in adoption of fuel-efficient technology. Revised standards might favor fuel-efficient imports over domestically made models (although the addition of imported models by domestic manufacturers to their product lines and the location of foreign-owned manufacturing plants here have considerably muddied this problem). Finally, Congress faces the choice of whether to allow fuel economy credits to manufacturers for vehicles that incorporate stringent emissions controls, dual-fuel capability, or additional safety features. (Some of these issues have been addressed in OTA testimony and are included in a separate OTA report on automotive fuel economy.)

Requiring More Fuel Efficient Replacement Vehicles—Other methods of creating a market pull for more efficient vehicles would be to require fleet owners (including Federal agencies) to purchase replacement vehicles from the most efficient in the applicable size class, with stiff penalties for failure to comply and waivers for appropriate circumstances. This would be similar to provisions for alternatively fueled fleet vehicles in nonattainment areas included in the Clean Air Act Amendments of 1990. This is one area where Federal procurement policies could affect oil use, since the Federal Government is perhaps the largest purchaser of new vehicles.[23]

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[21] See *Changing by Degrees*, supra note 4, pp. 165-166, and references cited therein.

[22] Steven E. Plotkin, Senior Associate, U.S. Congress, Office of Technology Assessment, "Legislative Proposals to Increase Automotive Fuel Economy and Promote Alternative Transportation Fuels," testimony before the Subcommittee on Energy and Power of the House Committee on Energy and Commerce, Apr. 17, 1991.

[23] See U.S, Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Governments: Government by Good Example?* OTA-E-492 (Washington, DC: U.S. Government Printing Office, May 1991).

Promoting Alternative Transportation Fuels and Vehicles

The successful commercial penetration of alternatively fueled vehicles requires:

- the manufacture or retrofit of alternative fuel vehicles in sufficient quantity,
- the development of an adequate refueling and service support infrastructure, and
- consumer acceptance.[24]

Among policy measures suggested to create a market-pull for alternatively fueled vehicles are the following: giving rebates or tax incentives to reduce the front-end costs of these vehicles compared to those of gasoline models; requiring private and government fleet operators to purchase or retrofit a minimum number of alternative fueled vehicles; and promoting industry and industry-government joint ventures to accelerate vehicle technology RD&D and commercialization. Under existing programs, the Federal Government could support continued RD&D on promising alternative vehicle technologies, such as electric vehicles and hydrogen vehicles, that would not be commercially ready or cost-effective within 5 years, but might be within an additional 5 to 10 years.

Development of an adequate refueling and servicing network could be aided by requiring refiners and large gasoline retailers to offer a certain percentage of alternative vehicle fuels through their existing networks; and increasing alternative vehicle fuel subsidies, such as those now offered for ethanol production, and revising, as appropriate, inadvertent regulatory impediments for commercial distribution of natural-gas vehicle fuels.

Consumer acceptance could be enhanced by better information and minimum product standards for alternatively fueled vehicles. Commercial fleet operators are highly sensitive to fuel costs and overall vehicle life-cycle costs because their fleets tend to be driven more than private vehicles. An informational program for fleet operators that set out the reliability and potential cost savings from alternatively fueled vehicles could also encourage commercial interest. Manufacturers and retrofitters could be required to warrant the performance and reliability of their vehicles and to back it up with effective customer service.

Reducing Vehicle Miles Traveled

Measures that discourage discretionary driving and encourage increased car pooling and use of available public transportation can save fuel by cutting vehicle miles traveled. Higher fuel costs (either from higher market prices or increased taxes) are believed to have some immediate impact on discretionary driving and mode choice, but the extent of such savings is unknown. Ways to reduce vehicle miles traveled include: car and van pool matching services, parking restrictions, higher parking fees, employer-based transportation, flexible or staggered work weeks, telecommuting, high occupancy vehicle (HOV) lanes, and bikeways.[25] In general, these measures require comprehensive, locally designed approaches and public and employer acceptance to be successful. Federal assistance or requirements that localities or regions develop contingency plans to reduce vehicle miles traveled might speed implementation in an oil import crisis. Through the Departments of Energy or Transportation, the Federal Government could fund additional studies of the effectiveness of such measures at cutting vehicle miles traveled and share the results with local governments.

Improving the Efficiency of Traffic Movement

Traffic management and control technologies can promote efficiency by keeping traffic running smoothly and at more fuel-efficient speeds. Measures to improving the flow of traffic include highway and street improvements to reduce congestion, such as the installation of sophisticated traffic signals, ramp meters, and redesigned intersections, as well as measures aimed at cutting the number of vehicles on the road, such as HOV lanes and staggered work hours. Strictly enforcing speed limits would also boost fuel savings. Congress could require State and local governments to give consideration to the oil savings potential of additional traffic efficiency measures in preparing transportation plans and might provide financial assistance for such planning or system improvements.

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[24] For a more extensive discussion see, *Replacing Gasoline*, supra note 19.

[25] See ch. 3 of this report. See also, *Changing by Degrees*, supra note 4, ch. 5.

Encouraging Domestic Oil and Gas Production

Oil replacement technologies can counter the effects of an oil import disruption, but will achieve their maximum replacement potential only if domestic production of oil is maintained at or near current levels and if domestic natural gas production increases to meet new demand. Policy options that maintain domestic production and encourage oil and gas exploration and development are thus part of any oil import replacement strategy.

Increases in the market price of crude oil, and perhaps of natural gas, can be expected to accompany an oil import shortfall. These, in turn, will generally increase the level of domestic exploration and development activity. Under the expectation of a prolonged supply disruption (and presumably higher prices) the response might be greater than that seen under previous intermittent oil price disruptions.

Because of the lead times of 10 years or more involved in developing frontier production, remote areas such as the Alaska National Wildlife Refuge (ANWR) and frontier offshore areas, even if they were opened to exploration and commercial quantities of oil or gas were found, would be of little relevance in responding to a significant oil import disruption within the next decade. The best hopes for maintaining and even slightly increasing domestic oil production in the near term lie in unrecovered oil in existing fields. In a previous OTA report, *U.S. Oil Production: The Effect of Low Oil Prices*, we noted that:

> The great majority of oil reserves added to the U.S. inventory during recent times has come from non-glamourous sources. Fully 70 percent of the total U.S. reserves additions during 1979 to 1984 came from drilling thousands and thousands of extension and infield wells in the United States' large inventory of discovered oilfields. The potential for continuing high rates of reserve growth in discovered oil fields at relatively low cost is one key to the future of U.S. domestic oil production in a low price environment.[26]

A wide range of legislative options has been proposed to encourage domestic exploration, development, and production. In general, they can be grouped as follows:

1. targeted tax incentives for exploration or production such as tax deductions, credits, depletion allowances;
2. measures that raise the price of oil or natural gas such as import fees or price floors;
3. technical assistance and technology transfer programs;
4. changes in the SPR program to favor certain classes of domestic producers or to include preservation of domestic production potential;
5. opening more Federal onshore and offshore lands to leasing, or adopting more favorable lease terms or royalties; and
6. resolving specific regulatory or environmental controversies that delay exploration, development, or production.[27]

All of these measures are politically controversial because they often conflict with other public policy goals such as increasing Federal revenues, reducing the deficit, restoring fairness in tax laws, eliminating energy subsidies, protecting the environment, protecting the international competitiveness of U.S. manufacturers, or promoting greater competition among energy sources and among suppliers. All approaches raise questions about whether they would actually spur incremental production, whether they would merely provide a general windfall, and whether any increased oil profits would be plowed back into exploration.

Our technical review found that the most attractive opportunities for maintaining domestic production over the near term were sustaining exploratory and developmental drilling activity in known fields, accelerating enhanced oil recovery, bringing shut-in or marginal oil fields back into production, and limiting the premature abandonment of existing wells. All of the policy options listed above, could in some way affect these prospects. Further study of the relative effectiveness, cost, and incremental oil yields from these options would be needed to determine which would offer the greatest benefits for reducing oil import vulnerability in the near term.

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[26] U.S. Congress, Office of Technology Assessment, *U.S. Oil Production: The Effect of Low Oil Prices*, OTA-E-348 (Washington, DC: U.S. Government Printing Office, September 1987), p. 75.

[27] For an extensive treatment of the pros and cons of policy options to aid the domestic oil industry, see National Petroleum Council, ***Factors Affecting U.S. Oil and Gas Outlook***, February 1987.

Enhancing Natural Gas Availability

Concerns over natural gas availability include not only the adequacy of domestic production, but also the ability to move gas from the wellhead to the burner tip. Natural gas use in some regions has been constrained because interstate pipeline capacity and storage facilities are insufficient to meet incremental demand. Planned capacity additions, new pipelines, and Canadian gas imports are reported to have faced delays in obtaining needed regulatory approvals. Changes in the FERC's procedures for approving new interstate pipelines to expedite regulatory review, while assuring that environmental and competitive issues are satisfactorily resolved, might enhance natural gas availability.

As an alternative to increasing pipeline capacity, some local distribution companies, electric utilities, and large industrial users are considering expansion of natural gas storage capacity, including natural gas liquefaction and storage facilities. Congress could require the DOE to review the technical, environmental, and regulatory issues associated with expanding gas storage capacity and to identify any appropriate legislative changes that may be needed.

Some areas also lack adequate local natural gas delivery systems, effectively foreclosing the gas conversion option for many potential customers. Congress might consider measures to encourage local natural gas distribution utilities and State regulatory authorities to review the adequacy of natural gas service and to seek ways to enhance the capability to add new customers. This would increase the potential for rapid gas-to-oil conversions in the event of a crisis.

Natural gas transportation fuels raise the related, but separate, issue of natural gas refueling stations for alternatively fueled vehicles and natural gas purchases by industrial and large fleet owners and service station operators. Congress and local regulatory authorities could create a special category for such operations exempting them from regulation as public utilities. In addition, Congress could ask DOE to examine whether additional incentives or Federal requirements are needed to encourage the rapid development of a natural gas transportation refueling and service infrastructure to meet the needs of private and government fleet owners.

Reexamining Oil Import Disruption Planning and Emergency Response

Because technical means alone would not be sufficient to offset the loss of oil imports in a major and prolonged supply disruption, the availability of strategic and private stocks and oil emergency contingency plans and authorities assume a greater importance. As imports rise, the amount of oil needed for the SPR will also have to increase. Congress recently approved a 1 billion barrel fill level for the SPR, but this will not be reached until the late 1990s. Congress also approved the creation of oil product reserves.

In light of the recent experience with the Iraqi invasion of Kuwait, Congress may wish to consider additional refinements of the SPR system. For example, provisions authorizing the release of oil from the SPR might be clarified to allow SPR sales to respond to sharp, panic-driven increases in the price of oil, in the absence of any physical shortage. A mechanism might be added to accelerate the SPR fill rate and to raise the SPR maximum to maintain adequate levels of reserves. Additional purchases might be authorized to take advantage of low oil prices, for example. Alternative SPR financing mechanisms might also be considered.

Under the Defense Production Act and energy emergency legislation passed in the late 1970s, the President and the Secretary of Energy were given extensive authority to respond to an oil supply crisis by instituting rationing, driving restrictions, and other emergency conservation and allocation measures. Some of these authorities have lapsed, and many contingency plans were never developed fully. Congress may wish to reexamine the adequacy of existing law for responding to prolonged oil import disruptions and to assure that oil emergency plans are kept up-to-date.

OTA's 1984 report noted that the Federal Government was ill-prepared to respond to an oil supply crisis, or even to monitor our capability to deploy oil replacement technologies and the rate of oil replacement. Among options that could be taken in advance of a crisis to redress these shortcomings are collecting and maintaining accurate information on investments in oil replacement technologies, and establishing standby oil replacement incentives and taxes. In the event of an oil supply shortfall, the government could rely on the investment monitoring system to determine whether the rate of oil replacement was proceeding effectively. If investments were occurring too slowly, and market intervention seemed desirable, then standby taxes and financial incentives could be activated and increased or modified, as needed, to be sufficiently effective.[28] The advantage of such a strategy is that it allows a flexible and well-defined government response that can be adjusted, depending on the market behavior and the response to various levels of incentives. Since our 1984 report, government information collection and reporting have improved only slightly, but are not specifically directed at providing the kinds of timely information and analysis that would be needed in a crisis.

POLICY OPTIONS FOR REDUCING OIL IMPORT VULNERABILITY AS PART OF OTHER NATIONAL POLICY OBJECTIVES

The prospect of a prolonged and severe oil import crisis, as assumed in our technical analysis, may be remote, but not implausible—and the impacts on the economy and our way of life could be devastating. OTA has previously addressed the issue of reducing oil import vulnerability in testimony on national energy goals and in a related report on energy technologies for the future.[29] We stressed that energy security can be viewed not only in terms of a short-term contingency plan, but also from a long-term perspective embracing broader and more fundamental national goals of economic health, environmental quality, and national security. Developing a national energy strategy requires a delicate balancing of energy security with these other objectives. Some energy options advance all three national goals. Others, particularly those that improve efficiency of production and use, support one goal but run counter to the others. For example, increased reliance on coal and methanol transportation fuels from coal could cut oil import dependence but exacerbate problems of air pollution and global climate change.

There are no quick and easy technical solutions to America's oil import dependence. Major changes in energy systems—and major changes are what would be needed—require decades and unwavering commitment from citizens, political leaders, and industry. A major turnover of the existing capital stock of energy supply and consuming equipment will take a long time. In the absence of a supply crisis, short-term strategies—either to spur production or to curb consumption—could prove inefficient and traumatic.

The same oil replacement technologies and policies that could prove critical in an oil import crisis also can contribute to achieving a long-term goal of reducing import vulnerability. Indeed, many of these technologies offer more significant savings over the longer term than they do as short-term replacement options. For example, improving total automobile fleet fuel efficiency and a transition to alternative vehicle fuels both are more effective as long-term rather than short-term options. The additional time for technology development and institutional change under a long-term oil replacement strategy would also enhance the effectiveness and reliability of other technologies. Over the longer term, new technologies, such as electric vehicles and fuel cells, could reach commercial viability. In short, a long-term oil replacement strategy offers more technology options than a crisis scenario.

Setting National Energy Policy Goals

We can ease oil import vulnerability if we establish long-term energy goals . . . and stick to them through periods of both crisis and calm and through high and low oil prices. A sensible, comprehensive energy policy must, of course, be responsive to sudden changes of events, but it must be fundamentally grounded in long-term strategies.

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[28] U.S. Congress Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability,* OTA-E-243 (Washington, DC: U.S. Government Printing Office, September 1984) available from the National Technical Information Service, Springfield, VA 22161, (order #PB 85-127 785/AS), pp. 26-35, p. 29.

[29] "Energy Policy Context for the 1990's: Considerations for a National Energy Strategy," testimony of John H. Gibbons, Director, U.S. Congress, Office of Technology Assessment, Before the House Committee on Energy and Commerce, Subcommittee on Energy and Power, Feb. 20, 1991. "On Energy Perspectives," testimony of John H. Gibbons, Director, U.S. Congress, Office of Technology Assessment, Before the House Committee on the Budget, Oct. 24, 1990; and testimony of John H. Gibbons, Director, U.S. Congress, Office of Technology Assessment, Before the Senate Committee on Energy and Natural Resources, Oct. 2, 1990. U.S. Congress, Office of Technology Assessment, *Energy Technology Choices: Shaping Our Future,* OTA-E-493 (Washington, DC: U.S. Government Printing Office, July 1991), chs. 1 and 5.

The time may have come to make an explicit commitment to a smooth, multidecade transition to the post-fossil fuel age while constantly advancing our energy efficiency. Doing so at minimum cost will require several decades to stabilize our dependence on imported oil, and possibly a century, to get beyond fossil fuels. Our long-term economic, environmental, and national security future could well depend on the success of these transitions, and the specter of global warming could greatly foreshorten the time in which we once thought we could depend on fossil fuels. The relationships among the long-term goals of economy, environment, and security provide some important guiding principles—principles from which a systematic, integrated, and comprehensive energy strategy that is responsive to all three goals can logically follow.

In many ways, Congress acts as a supreme board of directors for our national enterprise, setting broad policy goals, approving plans to reach these targets, and periodically measuring progress and recharting direction. To establish a comprehensive national energy strategy, Congress could set broad, long-term energy policy goals and approve the implementation plans and programs submitted by the President and the Secretary of Energy (these implementation programs would likely include many of the oil replacement options previously discussed under the oil disruption response strategy). To aid in oversight, Congress could direct the Secretary to develop quantitative indicators of our progress in attaining our targets and to report on them periodically. The Secretary might also be required to include in any legislative requests a statement of how new energy programs or appropriations would advance the national energy goals. Congress would review the goals every 5 years and make any necessary modifications or additions.

Candidate goals for limiting oil import vulnerability, increasing energy efficiency, and beginning a long-term transition to a post-fossil economy by the year 2010 might include, for example:

1. limiting U.S. net oil imports to not more than 50 percent of annual oil consumption;
2. diversifying sources of world oil production in regions outside the Middle East, when such assistance can be aligned with other U.S. policy interests;
3. increasing U.S. energy efficiency (energy per unit of domestic output) by 20 percent per decade or an average of 2 percent per year;
4. initiating a long-term transition to a post-fossil economy by reducing carbon intensity by 10 percent in each of the next two decades (equivalent to an average reduction of 1 percent per year);
5. improving the efficiency of the U.S. transportation sector by increasing light-duty vehicle fuel efficiency by an average of 2 percent per year; and
6. reducing oil's share of U.S. transportation energy use by 10 percent by 2010.

Having adopted comprehensive national energy policy goals and an implementation plan for achieving them, other policy initiatives and legislation could then be evaluated based on how they contributed to achieving those goals. For example, an underlying objective for federally supported technology RD&D and commercialization programs would be to identify and advance promising technologies to achieve these national energy goals.

Capping Oil Imports

Dramatic and sustained efforts would be required to hold down oil import dependence over the next several decades—even to a level of 50 percent. There are major opportunities to improve efficiency in all sectors and to shift industrial, residential, and commercial oil use to other sources such as natural gas or electricity. Capitalizing on these opportunities can provide good jobs and boost domestic economic activity. To the extent that we improve efficiency, supplies will last longer, economic competitiveness will improve, environmental problems will be eased, and international tensions will be lessened. Supply-side mechanisms to limit import dependence include sustained domestic oil and gas production and the development and production of alternative transportation fuels.

Diversifying World Oil Production

The growth of oil production outside of the Organization of Petroleum Exporting Countries and the Middle East has lessened the ability of single nations to cut off world oil supplies and tempered the prospects for prolonged price disruptions. Surge production in areas outside of the Persian Gulf helped offset the loss of Iraqi and Kuwaiti oil, for example. Because oil is a globally traded commodity, the United States can encourage, to a certain extent, the oil development efforts of other nations, thus easing pressures on world markets and prices. This can often coincide with other policy objectives. For example, helping the Soviet Union expand its oil production could have several benefits. First, the Soviet Union contains major sedimentary basins that offer great potential for exploration and development Second, success in increasing Soviet oil exports would not only diversify world production (and possibly U.S. imports) but also would provide the Soviets with the hard currency so badly needed to maintain peaceful progress toward a viable market economy. The Soviets are already significant oil exporters, but economic difficulties in that nation have threatened continued production. One prominent energy analyst has even suggested that the next oil shock might originate not in the Mideast, but in the loss of Soviet exports.[30] There are also opportunities to assist petroleum development in sister nations in the Western Hemisphere through technology transfer and joint ventures in research, exploration, and production. Massive reserves, for example, exist in Venezuela, some of which (e.g., the heavy oils in the Orinoco Basin) can benefit from further research.

Improving Energy Efficiency

OTA's studies over the past decade have consistently shown that energy efficiency is an essential cornerstone to a comprehensive energy policy framework. Overall energy intensity of the U.S. economy fell 2.5 percent per year over the last decade, most of which was due to improved efficiency. The growth in electricity use, historically greater than that of the economy, has fallen back to the same rate of change as the GNP. Moreover, these efficiency gains have generally come about with net cost savings. Considerable gains in future energy efficiency are still possible in all sectors of the economy using existing technology. Even greater savings in cost and efficiency will be possible with technologies under current R&D. A goal of sustained energy-efficiency improvement of 2 percent per year for the next two decades is realistic for the United States. With more vigorous research on energy efficiency, coupled with leadership and investment, this goal can be met or exceeded—and with options that are no more costly than pursuing the supply-side path. Moreover, pursuing such a goal appeals to all three policy interests of economic health, environmental quality, and national security.

Long-Term Transition to a Post-Fossil Economy

For decades we assumed that fossil fuels could supply our energy needs for several more centuries. Thus our major commitment to a nonfossil future has been our work on harnessing nuclear power—fission and fusion. While nuclear fusion remains a frustrating and elusive goal, nuclear fission now accounts for 20 percent of U.S. electricity generation, or about 8 percent of our total primary energy budget. Other nonfossil sources (mostly hydroelectric power) add another 4 percent, so our present nonfossil energy production is about 12 percent. But the nuclear fission enterprise, for several reasons, is in deep trouble—so deep that rescuing it could well be more difficult than the original task of creating it. And our long-term efforts to harness solar energy—directly or indirectly through wind, biomass, hydropower or other means have been very limited.

The rising specters of air pollution and climate change casts an ominous shadow over the fossil era, accelerating its possible demise to within a century or less. This means that unless we ignore, at our peril, global climate change we must consider solar and nuclear power (both fission and fusion) as new, potentially globally dominant energy sources, perhaps within 50 years. Developing and preserving nuclear and solar options will entail long-term commitments of research, development, and investment that requires us to begin that odyssey now.

With this imperative, a candidate goal for U.S. energy policy is to reduce the carbon intensity of our energy use on average 1 percent per year for the next two decades. The number we choose for this goal is less important than the will to pick a number and vigorously pursue it with a multipronged commitment to technology research, development, demonstration, and commercialization across all energy sectors. Energy efficiency improvements would dominate the first decade, securing time to allow alternative transportation fuels and alternative, nonfossil sources for electric power generation to develop systematically and efficiently.

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[30] Daniel Yergin, "The Next Oil Surprise," *The New York Times Magazine*, part 2, Dec. 2, 1990, pp. 8, 26.

Improving Energy Efficiency in Transportation

OTA believes that there *is* a substantial potential for further fuel economy in transportation through purely technological means (i.e., without major changes in consumer choice), but the magnitude of this potential within the next decade is less than we would like. Our best estimate for this potential is for a new car fleet fuel economy in the absence of a crisis of about 30 miles per gallon (mpg) by 1995 and 37 mpg by 2001, both values measured according to the EPA's test procedure.[31] Longer term progress, beyond the year 2000, could be much greater if strong continual incentives for fuel economy are brought to bear on the industry. If Congress believes that even larger gains in fuel economy are necessary beyond that which can be achieved with strictly technical fixes, it could mandate a basic shift in the size and performance of the fleet either through regulatory or economic means.

Cutting Oil Dependence in Transportation

Non-oil-based liquid fuels are an important adjunct to increased fuel economy and increased domestic oil production in reducing U.S. dependence on imported oil. A recent OTA analysis of several alternatives to gasoline[32] shows that alternative fuels present a key opportunity to reduce U.S. oil dependence. Over the next few decades, alternative fuels derived from natural gas—methanol and compressed natural gas—and from biomass should be capable of substituting for a significant fraction of transportation petroleum use. The worldwide resource base for natural gas is very large, and considerable volumes of undeveloped gas resources exist outside of the Middle East, including large volumes in the Soviet Union. Electric vehicles, perhaps employing not only batteries but fuel cells or other hybrid engines, could also be important possibilities in some regions of the United States. This, of course, depends on the pace of R&D and the constraints on other options. The pace of progress is promising. For example, California has passed legislation requiring deployment of some "ultra-low polluting" vehicles, which should force commercialization of alternatively fueled vehicles.

In the long term, we must chart a course beyond fossil fuel dependence in transportation—that means electricity and hydrogen, both obtainable from nuclear and solar sources. But both have serious cost, engineering, and political constraints and will require a major development effort. Over the next several decades, however, these options could greatly diminish greenhouse gas emissions by progressively replacing fossil-based transportation fuels. Developing the technology, the support infrastructure, and consumer acceptance of nonfossil vehicles will be a formidable challenge.

CONCLUSION

In confronting the prospects of continuing oil import vulnerability, the United States has three choices. We can continue on the current path and wait until the next disruption occurs before deciding on further action. We can anticipate that such disruptions will occur and set in place effective measures that enhance our ability to replace oil in response to the disruption. Or, we can begin now to craft a more comprehensive national energy strategy that embraces a long-term goal of reducing our reliance on oil and other fossil fuels and beginning a transition to the eventual post-fossil era, and that does so consistent with other national policy goals. Whichever path we choose, success in reducing our oil import vulnerability will require a strong Federal example and the sustained support and cooperation of citizens, business, and government.

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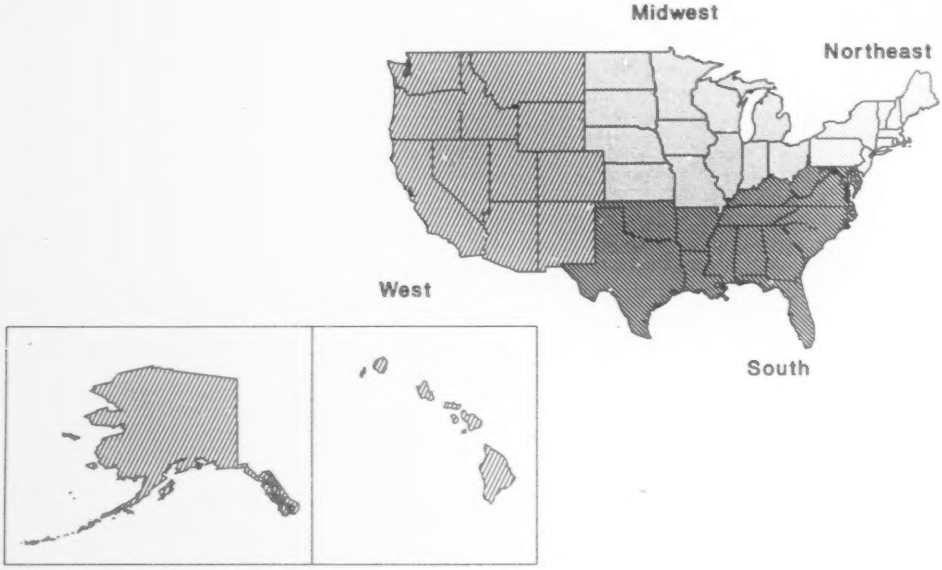
[31] Steven E. Plotkin, Senior Associate, U.S. Congress, Office of Technology Assessment, "Estimating Levels of Corporate Average Fuel Economy," testimony before the Senate Committee on Energy and Natural Resources, Mar. 20, 1991.

[32] *Replacing Gasoline*, supra note 19.

Appendix

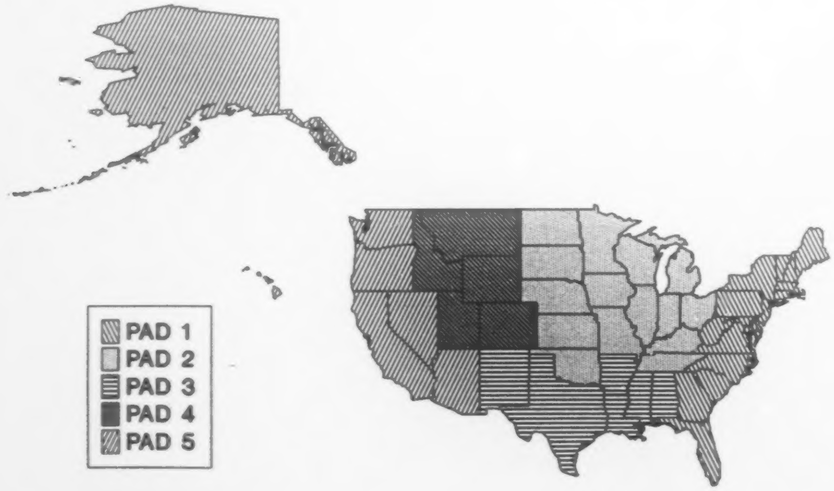
Appendix A
Reference Maps

Figure A-1—Map of U.S. Census Regions


Midwest
Northeast
West
South

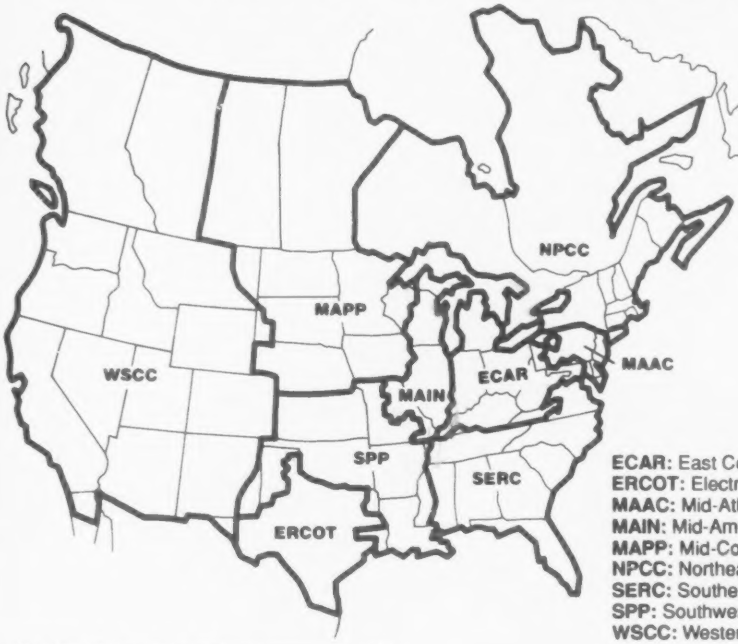
SOURCE: Office of Technology Assessment, 1991.

Figure A-2—Map of Petroleum Allocation for Defense (PAD) Districts


▨ PAD 1
▢ PAD 2
▤ PAD 3
■ PAD 4
▨ PAD 5

SOURCE: Office of Technology Assessment, 1991.

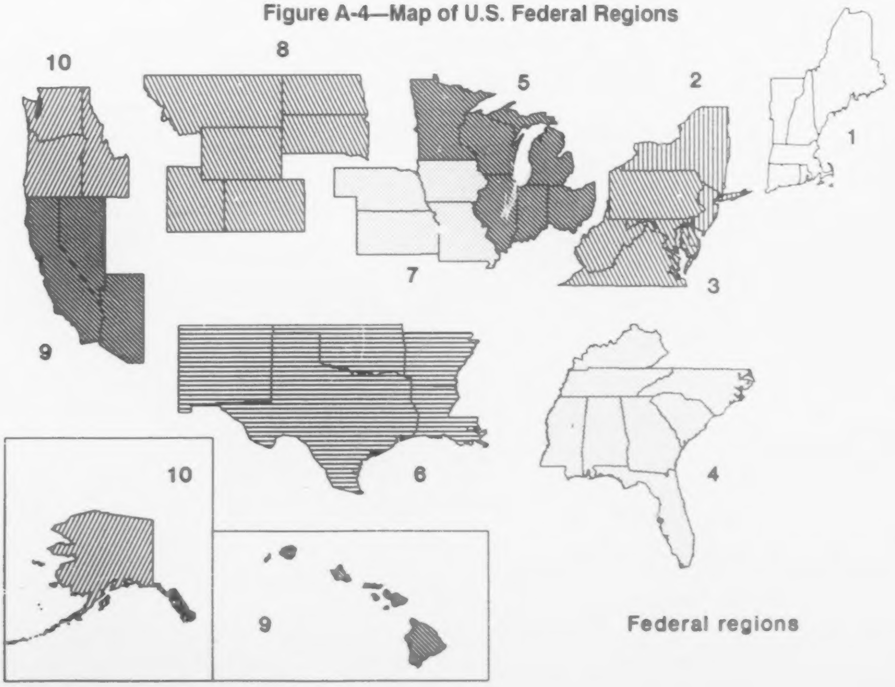
Figure A-3—Map of North American Electric Reliability Council (NERC) Regions


NPCC
MAPP
MAAC
ECAR
MAIN
WSCC
SPP
SERC
ERCOT

ECAR: East Central Area Reliability Coordination Agreement
ERCOT: Electric Reliability Council of Texas
MAAC: Mid-Atlantic Area Council
MAIN: Mid-American Interconnected Network
MAPP: Mid-Continent Area Power Pool
NPCC: Northeast Power Coordinating Council
SERC: Southeastern Electric Reliability Council
SPP: Southwest Power Pool
WSCC: Western Systems Coordinating Council

SOURCE: Office of Technology Assessment, 1989.

Figure A-4—Map of U.S. Federal Regions


10
8
5
2
1
7
3
9
6
4
10
9
Federal regions

SOURCE: Office of Technology Assessment, 1991.

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